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IMCC SYSTEMS AND PERFORMANCE REQUIREMENTS SPECIFICATION

(Contract No. NAS 9-366)

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PHILCO

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WDL Technical Report E120

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Submitted to the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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Houston, Texas

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FOREWORD

This effort, on the "Design and Development Study for Manned Space Flight Operations Control and Support," is composed of eight major areas, which are documented separately. Some of these areas of study may be further subdivided but are reported in the same series of documents because of their interrelated nature. These eight report areas are described briefly in the following paragraphs. This report covers progress to date on the study area listed in Item 3 below:

1. <u>Facility Requirements and Criteria - TR-E112</u>

   This report documents information pertaining to the overall IMCC building configuration to house the operational and support systems necessary to the control and support of Manned Space Flight Programs. Contained within this series of documents are overall building dimensions, the allocation of space for major systems and subsystems, and the primary and standby power and air conditioning estimates for the equipment considered necessary for operations.

2. <u>Information Flow Plan (Gemini Rendezvous Operation) - TR-E114</u>

   This report contains three major elements; information flow requirements, information flow plan, and operational concepts and procedures. These elements are analyzed both by phase of mission and by function. Phases include checkout, countdown, powered flight, orbital operations with emphasis on rendezvous, reentry, and recovery. Major functions include flight dynamics, spacecraft systems, life support systems, network control, launch operations, and recovery operations. These reports also discuss the manning of these functions.

3. <u>IMCC Systems and Performance Requirements Specification - TR-E120</u>

   The study in this area encompasses the specification of the basic systems for Gemini (rendezvous), Apollo earth orbital and Apollo lunar operations, and the specification of an integrated system, the performance of which will accommodate all three mission classes without major revision. The major IMCC systems in this area of study include communication, computation (interface), display/control, simulation and checkout, and the local "remote site".

4. Information Flow Plan Development (Manned Apollo Missions) TR-E121

   This series of reports, as in item 2 above, contains information flow requirements, information flow plan, and operational concepts and procedures for manned Apollo earth orbital and lunar missions. Information is presented both by mission phase and by function. The functions covered in this report are essentially the same as for the E-114 series. The phases, however, include checkout, countdown, earth orbit, translunar flight, lunar orbit, lunar operations, transearth flight, reentry, and recovery, as appropriate. Manning concepts are discussed as they relate to control and support of these operations.

5. GOSS Performance Requirements Specification - TR-E122

   This report translates the information flow requirements into terms of the performance required of ground equipment to support Gemini (rendezvous) and manned Apollo missions. It integrates these requirements so that like requirements for different missions may be accommodated by the same classes of equipment. Of equal importance is the difference between mission requirements (for example, between earth orbital and lunar missions) and the impact on support requirements. Performance both within phases and the transition between phases are documented.

6. IMCC Procurement Plan - TR-E125

   This report will contain procurement information on typical systems and subsystems which perform the functional operations within the IMCC. It will present scheduling information on such items as require long lead times and development effort, and transportation and installation times. It is not intended to be a full-blown procurement document which typically includes identification of all of the components and characteristics of these, but rather will provide data which will demonstrate the feasibility of achieving the target schedule dates.

7. IMCC Functional Checkout Plan - TR-E126

   This report will contain the general plan for the initial checkout of the IMCC systems both prior to acceptance and after installation. It will also include documentation on the scheduling of checkouts once the facility is in operation and will include the intended use of the simulation and checkout system to facilitate this checkout. Personnel and equipment required specifically for systems checkout will be identified as part of the plan.

8. IMCC Functional Maintenance Plan - TR-E127

   This report will discuss the plan for maintenance of IMCC operational systems. It specifically excludes facility maintenance. Procedures for preventive and routine maintenance and the continuation of operations under these conditions will be discussed. Considerations of minimum interference to operations will be delineated. Information concerning logistics, spare parts, personnel, maintenance equipment, etc., will be included.

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SECTION 1
INTRODUCTION

This report presents preliminary system and subsystem requirements and specifications for the Integrated Mission Control Center (IMCC) in support of the rendezvous phases of Project Gemini and Project Apollo Primary emphasis is given to the mission support requirements for Gemini with due consideration to also accommodate the future phases of Project Apollo, within the constraints of current information.

These performance requirement specifications reflect a maximum integration of the IMCC equipment in support of both Gemini and Apollo.

The IMCC performance requirements are based upon the continuing detailed studies and development for the overall mission information flow plan, as presently reflected in WDL-TR-E114-2, Information Flow Plan (Gemini Rendezvous Operation), dated 9 July 1962, under this contract. The report covers the considerations relating to display console, data processing, operational simulation and training, GOSS interface and communication requirements.

This report is divided into eight sections, entitled as follows:

Section 1	Introduction
Section 2	Overall IMCC Performance Requirements
Section 3	Communication System
Section 4	Data Processing System
Section 5	Display/Control System
Section 6	Simulation and Checkout System
Section 7	MSC "Remote Site"
Section 8	References

Section 2 summarizes the IMCC functional system requirements which are based on the overall mission information flow plan as described in WDL-TR-E114-2. Section 3 presents the IMCC communication system which is required to accommodate the flow of information within the IMCC, as well as the interface with the remote elements of GOSS.

Section 4 covers the data processing system required to support the functions of display, real-time computation, and input-output data scanning and formatting requirements.

Section 5 describes the display/control system covering requirements, techniques and recommended configurations for group and console displays.

Section 6 presents the requirements and concepts covering the operational simulation and checkout system to accommodate the mission requirements.

Section 7 presents the considerations involved in a "remote site" within the IMCC which is recommended for primary use in simulation, training and checkout. In addition, its potential use as an operating "remote site" station is also presented.

Section 8 lists the other documents referenced in this report.

Future revisions of the report will describe the IMCC systems requirements in support of earth orbital and lunar Apollo missions also. The IMCC systems to support the requirements of both Gemini rendezvous and Apollo missions will be integrated into one flexible group of systems capable of supporting each of these missions.

SECTION 2
OVERALL IMCC PERFORMANCE REQUIREMENTS

2.1 IMCC FUNCTIONAL REQUIREMENTS

2.1.1 General

The prime function of the IMCC is to exercise operations direction and technical management for Manned Space Flight Programs in all aspects of ground support from the beginning of countdown through flight operations to recovery. Actual control of the manned spacecraft, however, rests ultimately with the astronauts. The IMCC function includes the direction of the Ground Operational Support System prior to and during a flight mission or simulated mission, and, more importantly, the transmission of information, advice, and recommendations to the astronauts as to the appropriate action to be taken under a specific set of circumstances consistent with flight plan objectives and mission rules. The IMCC also controls certain aspects of the flight of unmanned vehicles.

The specific functions of the IMCC which are required to effect the necessary direction and control fall into three major categories:

a. Pre-flight operations
b. Mission operations
c. Non-mission operations.

The IMCC functions in each of these phases are discussed below and are discussed in greater detail in reference 1.

2.1.2 Pre-Flight Operations

There are a number of IMCC functions which must take place as part of pre-flight (or pre-launch) operations. These functions relate primarily to planning, simulation, testing, and checkout. These functions include the following:

a. Perform support and operations planning for missions
b. Develop and perform simulation and training exercises
c. Conduct briefings and de-briefing on all exercises
d. Plan IMCC and remote site checkouts
e. Monitor pre-launch booster and vehicle checkout
f. Prepare flight plans and mission rules
g. Prepare staffing plans for missions
h. Assist and coordinate recovery planning.

2.1.3 Mission Operations

Mission operations span all phases of operation from the beginning of countdown to post-flight debriefing.

Prior to launch, the IMCC functions are concerned primarily with GOSS readiness and estimated launch time. From launch to recovery, these functions include: (1) direction of the GOSS network, (2) monitoring mission status, (3) predicting contingencies and reacting to them, and (4) providing advice to the astronauts and some control of unmanned spacecraft. (See Reference 1.)

Specific functions in each of these categories are listed below.

2.1.3.1 Direction of GOSS Network

a. Provide communication termination and switching facilities for the GOSS network

b. Monitor and control voice, TTY, high-speed and low-speed data links to remote sites, the launch complex and the primary recovery control centers

c. Monitor and control voice and data links to the spacecraft

d. Transmit voice and digital data to the GOSS elements and to the spacecraft

e. Schedule the use of GOSS stations and equipment during mission periods

f. Schedule voice, data, and video loops during mission operations

g. Compute nominal acquisition data for each remote station and transmit these data to the remote stations. This information should include time and pointing instructions for spacecraft acquisition (on the horizon), five degree acquisition, fifteen degree acquisition, and minimum range acquisition. The acquisition information should also include communication data resulting from the checkout and launch tests on both the Gemini and Agena. Such communication data will facilitate the establishment of ground-to-vehicle links

2.1.3.2 Monitor Mission Status

a. Provide group displays showing overall mission status

b. Provide detailed action displays for flight control and support personnel

c. Maintain status information on all recovery forces in terms of location, assistance, and recovery periods for each designated area

d. Provide mission status information to VIPs, press, and other agencies

e. Monitor Gemini and Agena systems during checkout and launch for possible hold decisions and for engineering analysis. If there is a change in the status of the propulsion or guidance systems, for example, it may be necessary for the IMCC to perform computations to determine the possible effects on rendezvous and for the IMCC Flight Director to recommend a hold decision or mission alteration to the Operations Director.

f. Compute and monitor vehicle ephemeris

g. Compute and monitor orbit capabilities of both vehicles

h. Make go, no-go decision on Gemini insertion

i. Compute and monitor, in conjunction with the Launch Conductor, the launch time for the Agena (assumed to be launched second) within the launch window. These computations will be based on injection conditions and the resultant orbit of Gemini and the status of both vehicles insofar as status affects rendezvous.

j. Predict landing point, landing time and the associated uncertainties

k. Monitor all spacecraft telemetry including: (1) propulsion status of spacecraft in terms of remaining fuel, predicted safety factor, and expected time-to-shortage; (2) spacecraft pneumatic, life support, navigation and guidance, attitude control, and other electronic and mechanical control systems; and (3) insertion conditions for Gemini and the Agena.

2.1.3.3 Transmission of Instructions to Crew and to Spacecraft

a. The final phases of rendezvous will be the sole responsibility of the spacecraft crew. The IMCC must provide the crew with the necessary information regarding the status and attitude of the target vehicle, and the required maneuvers necessary to effect docking. These recommendations will be based on the orbital elements of both vehicles and the docking devices in both vehicles. Should collision be imminent and normal docking impossible, it will be the responsibility of the IMCC to determine the appropriate commands and time of execution to the target vehicle to change its orbit to avoid collision if this maneuver cannot be controlled from the manned spacecraft. Such determinations will be based on the orbital elements and attitude of each vehicle, the energy status or reserve of each vehicle, and the possibility of a second attempt to rendezvous, should it be desired.

b. During the final phases of rendezvous, it may be necessary to adjust the attitude of the target vehicle. The attitude-adjust commands and the time of the execution will be determined by the FDO. It may also be desirable to control the attitude of the target vehicle after the two vehicles have been separated to permit the target vehicle to re-enter in the desired manner. The determination of attitude control commands and the time of execution will be based on the orbital elements of both vehicles, information on the attitude, and energy status of the target vehicle.

c. After rendezvous of the two vehicles has taken place and the desired maneuvers have been completed, it will be necessary to return the Gemini vehicle to the ground. This will involve separation of the target vehicle and the Gemini vehicle. The separation will be the sole responsibility of the crew. The FDO will be responsible for advising the crew during these phases of flight, and to initiate engine re-start or attitude control commands, as required, for the Agena vehicle to achieve the desired separation, if the spacecraft crew cannot perform this function once separation has been achieved.

d. Recommend to the crew a duty cycle program for the spacesuit. This program will be a schedule of utilization of the life support systems in the spacecraft and the spacesuits. Coupled with this schedule will be recommended gas constituent flow rates.

e. Recommend optimum food consumption program for the extended missions

f. The maneuvering during the final descent of the Gemini vehicle will be the sole responsibility of the vehicle crew. The IMCC will be responsible, however, to make recommendations as to maneuvers required during the final descent to test lifting devices or to avoid local hazards. The recommendations may be based on information received from the Recovery Control Center and available knowledge of the status of critical vehicle systems, the crew's control capability and the overall mission objectives of the flight. It is recognized that communication may not always be possible during the descent.

2.1.3.4 Predict Contingencies and Solutions

a. Modify, add to, delete, or interpret mission rules

b. Maintain continually an abort plan which will consist of planned retrofire times for each orbit. It will be the responsibility of the Flight Dynamics Officer (FDO) to evaluate the optimum time for re-entry of the Gemini vehicle. The FDO will be responsible for recommending both the time of application of retrothrust and the attitude during the thrust application. This recommendation may simply involve the initiation of a time sequence. In this case, it will be the responsibility of the FDO to determine the start time of the retrosequence and provide this to the vehicle crew, such that the re-entry maneuver can take place automatically or under the control of the crew in the desired manner. The recommendations of the FDO will be based on the status of recovery forces, the conditions of the Gemini vehicle and the capability of the crew to maneuver during re-entry.

c. Analyze and evaluate spacecraft telemetry for possible trends, hazards, or contingency situations including radiation hazards, gas composition in the spacecraft and spacesuits, crew status and performance for possible mission alterations.

2.1.4 Non-Mission Operation

2.1.4.1 Data Analysis

During non-mission operations, the IMCC will be responsible for mission preparation activities. This preparation will involve analysis of the data from previous missions and planning of GOSS utilization for the upcoming mission.

2.1.4.2 Mission Simulation and Checkout

The IMCC must provide facilities for conducting IMCC remote site and integrated simulation for training, qualification, and checkout prior to a flight mission.

2.1.4.3 GOSS Status

During non-mission periods, the IMCC will also be responsible for collecting and maintaining status information on all GOSS elements.

2.1.4.4 Public Information

The IMCC will disseminate data for general public information.

2.1.4.5 Maintenance

The IMCC must provide logistic support and maintenance for the IMCC technical facilities, including the necessary aids for all maintenance activities, such as servicing, trouble shooting, adjusting and calibrating, removing and replacing of components, and repair of faulty units. This subject will be covered in greater detail in a subsequent report. The maintenance concept must complement the maintainability goals which affect design of the IMCC. Design goals for maintainability and reliability are presently being defined, and will be included in later revisions of this document.

2.1.4.6 Engineering Analysis

Activities relating to improvement or design of equipment and procedures involving the use of Laboratory Facilities for development and computers for analysis are included as typical non-mission engineering functions.

2.1.4.7 Administrative Support

This includes such activities as administration, security, travel, finance, and related activities.

2.2 IMCC OPERATIONAL SYSTEM REQUIREMENTS

2.2.1 Operational System Concepts

These concepts have been delineated in Section 3.1.1 of Reference 2. However, to provide continuity for this report, they will be repeated here.

2.2.1.1 General

Several major operational concepts influence all aspects of the operation and are, therefore, presented at this point. These are:

a. The astronauts will be in command of spacecraft operations to the maximum extent possible. This restricts ground control of the spacecraft to those events which exceed the capability of spacecraft equipment or to those periods during which the astronauts are effectively incapacitated. This concept may be modified to accommodate flight objectives and mission rules. It will be the perogative of the astronauts to delegate other functions of spacecraft command as they deem desirable.

b. The IMCC will have operational responsibility and authority over the GOSS during all phases of the mission from the beginning of countdown through the flight mission to recovery. The IMCC will be likewise in complete command of all elements of the GOSS participating in a simulation exercise for Manned Space Flight Programs. It will be the perogative of the IMCC to delegate temperary authority or standardized control functions to subordinate organizations and outlying stations for specific aspects of a mission. Included within these delegated functions may be certain launch and recovery operations, and contingency command and control procedures to be implemented by outlying "command" stations.

c. The Data Processing System will be implemented such that most functions may be performed in part on any other computer. Changes in assignment will be by executive program. The desirability of this feature is particularly obvious in the event of a machine failure, at which time certain critical functions being performed by the failed machine may be assigned to any other machine. The maximum degradation which can result under this condition is a reduction in either capacity or time, proportional to the percentage of the failed machine. Such a philosophy also pays off in that it permits procurement of a minimum number of computers while still assuring high availability through backup. Safety of flight considerations necessitate hard wire switching between those machines used for simulation and those used for the flight mission.

d. All normal operations and as many predictable contingencies as can reasonably and properly be handled automatically, will be programmed for machine processing so that human operators may utilize their time in analyzing trends in the data. By this concept of operation, the GOSS mission controllers will be provided maximum practical assistance in predicting contingencies so that they can alert the astronauts to an abnormal condition and recommend the proper corrective action. In those situations where the condition had been previously analyzed and programmed into the computer, a computer output would supply the alternative courses of action to mission controllers for selection and communication to the astronauts. On the other hand, if the condition had not been foreseen, the mission controllers and associated support personnel would have recognized the abnormality at the earliest possible moment and would, therefore, have had the maximum amount of time to evaluate the situation and to make the best recommendation as to remedial action. Under normal operating conditions, the mission controllers would be planning for future phases of the mission, performing such operations as determining which alternate mission would be appropriate or what the most productive modification to the flight plan would be.

e. One flight mission and one simulation or checkout mission may be in progress simultaneously. This dictates that operational procedures and instrumentation capability must be such that each can be performed without interference to the other. Duplicate Mission Operations Control Rooms (MOCR) and necessary support are planned to implement this capability.

f. The "remote site" at the MSC shall serve as a typical input for simulation exercises, and shall serve as a test bed for system improvement of the IMCC or spacecraft instrumentation and procedures for Manned Space Flight Programs. It may also perform the function of an operational site to support mission flights.

g. All aspects of the operational system shall have maximum reliability since this is directly related to the safety of the astronauts. By the same token, the emphasis in operational system planning shall be on flexibility because of the variety of planned missions and the requirement for a quick reaction to different conditions during a mission. Therefore, redundancy of instrumentation is acceptable, but only after exhaustive evaluation of more ingenious, more economical approaches have failed to provide a reasonable solution.

h. The operational system of the IMCC shall be an integrated system, improving by evolution but not requiring a radical change between the Gemini rendezvous phase and the Apollo orbital phase, nor between the Apollo orbital and lunar phases, nor between intermediate, less distinct mission phases. The system design should be imaginative such that a minimum change is required for those missions which will follow the Apollo lunar flights, whatever they may be.

i. Normal recovery shall be a land recovery in either the United States or Australia. The system shall, in addition to accommodating normal recovery, effectively support deferred emergency recoveries which may occur at a specific time during each orbit and shall provide the wherewithal to support emergency recoveries at any time during orbital or lunar flights, as appropriate.

2.3 FUNCTIONAL SYSTEM CONFIGURATION

2.3.1 General

Three major operational systems support flight missions:

a. Communication System
b. Data Processing System
c. Display/Control System

In addition, various support systems are required for operation of the Integrated Mission Control Center. These are:

d. Simulation and Checkout System
e. Technical Support Facilities
f. Non-operational Facilities
g. Remote Site

The remote site is considered a functional part of the Integrated Mission Control Center and if used as an operational site in addition to its basic simulation and checkout functions, will implement direct voice communication between the IMCC and the spacecraft, real-time up-data transmission, and furnishing of tracking information and data to the IMCC. Except for the RF antennas, the "remote site" will actually be a physical part of the Mission Operations Wing.

The non-operational facilities include the office, support and laboratory areas required to house the Flight Operations Division charged with the responsibility for mission planning, mission execution (including flight control), mission evaluation, and administration and operation of the Integrated Mission Control Center.

2.3.2 IMCC Functional Systems

Figure 2.3.2-1 is a simplified block diagram of the functional systems within the Mission Operations Wing of the IMCC. All external communication lines from the GOSS network enter the IMCC complex through the Communication System. Within this system, the tracking and telemetry data, alphanumeric text, and teletype messages are separated and

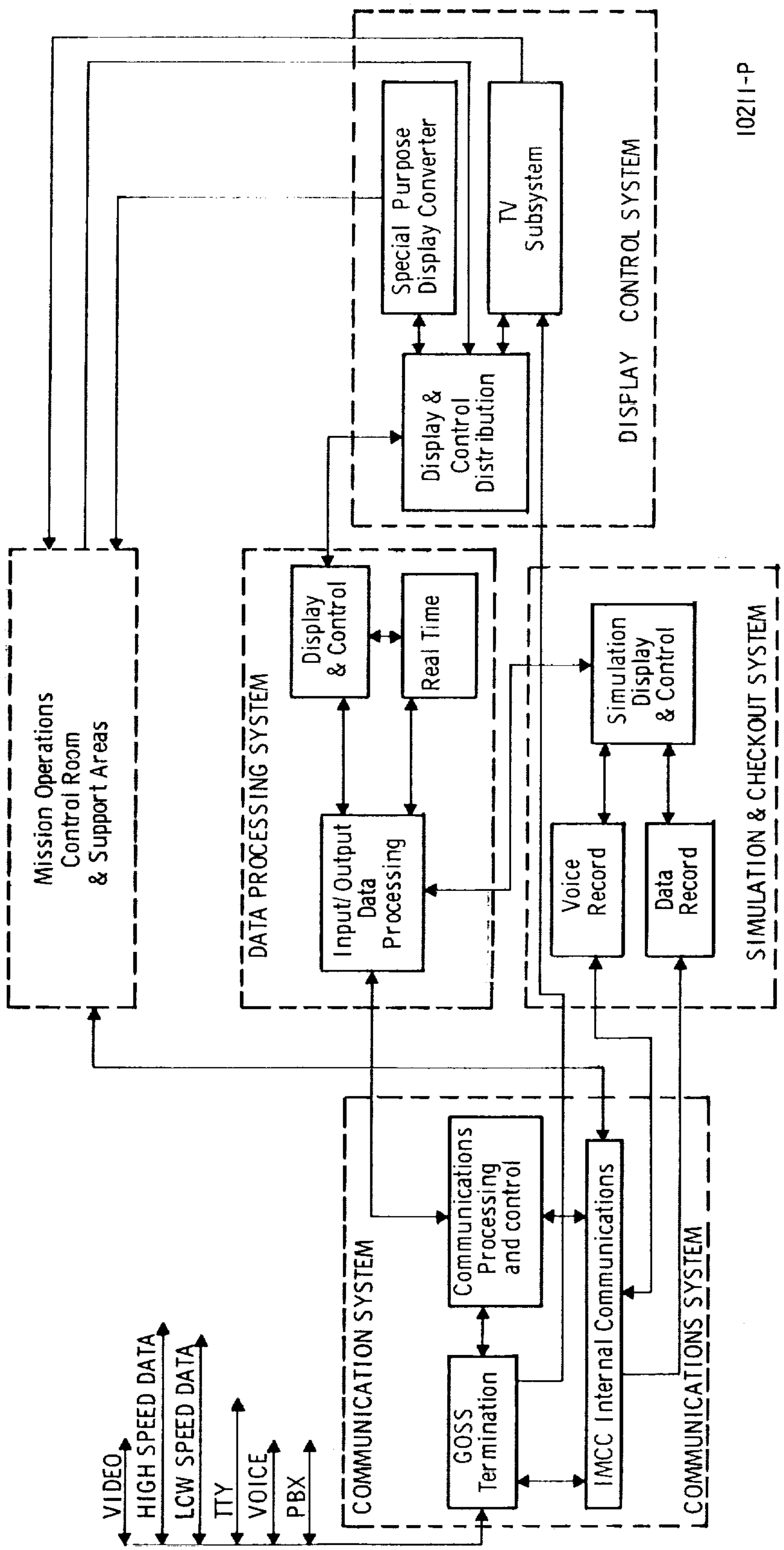

Figure 2.3.2-1 Simplified Block Diagram of IMCC Functional Systems

routed to their intended destinations, as indicated. During simulation exercises, the inputs from the Simulation System simulate inputs from the GOSS network, and follow the same distribution pattern. From the MOCR, paths are indicated to both the Communication System and the Display/Control System to provide for manual instructions and data call up from the IMCC and/or remote sites.

SECTION 3
COMMUNICATION SYSTEM

3.1 INTRODUCTION

The present GOSS communication network will be augmented and modified to accommodate the increased flow of information for the successful completion of the Gemini/Apollo missions. Its purpose is to maintain contact with the astronauts aboard the spacecraft, the tracking sites, and the launch and recovery control complexes for the interchange of intelligence, and to facilitate proper command decisions during launch, orbit, and reentry phases of the mission. The Integrated Mission Control Center, located at the Manned Spacecraft Center, will have overall operational cognizance of the worldwide GOSS communication network during the Gemini/Apollo missions.

This specification presents the performance requirements for the communication system within the IMCC to implement data flow in the GOSS. Although this specification, when complete, is intended to satisfy both Gemini rendezvous and Apollo requirements, the numbers and types of circuits in this issue primarily reflect the anticipated Gemini rendezvous mission requirements.

3.2 SYSTEM FUNCTIONAL REQUIREMENTS

3.2.1 General

The communication requirements for manned space flight missions comprise the following, but not necessarily in order of importance.

3.2.1.1 Mission Periods

a. Provide direct voice contact between the IMCC and the spacecraft

b. Provide voice capability between the IMCC, all support sites and other Government agencies

c. Telemeter biomedical data, environmental data, systems performance data, etc. from the spacecraft for display at IMCC

d. Transmit near real-time tracking data from the remote sites to the operational computers

e. Transmit computer-derived data from the IMCC to ground sites

f. Provide near real-time, ground-derived digital information to the spacecraft via remote sites

g. Transmit remote site status data for display at the IMCC

h. Inform remote sites of mission status

i. Support simulation and training

j. Transfer communication control to other agencies during non-mission periods

k. Provide other required operational information.

3.2.1.2 Non-Mission Periods

a. Provide voice capability between the IMCC, all support sites, and other government agencies

b. Provide non-real time command data from the IMCC to remote sites

c. Provide intersite communications.

These types of information must be transmitted between the remote ground facilities of GOSS and the Integrated Mission Control Center. This information is to be transmitted via high speed data (1200-2400 bps), low speed data (75-100 bps), teletype or voice circuits. The transmission media for these circuits entering the IMCC consist of normal 3 kc voice lines, specially-treated 3 kc voice lines for high speed data and normal 100 wpm bandwidth teletype circuits. These circuits, all arranged for four wire, full duplex operation, will arrive at the IMCC via leased commercial facilities, pass through the communication control room which houses the local technical control facilities for monitoring all lines, and terminate at the communication processor, which is the heart of the IMCC communication system and the primary control point for routing and switching of data and text messages within the IMCC.

3.3 COMMUNICATION SYSTEM RECOMMENDATIONS

The IMCC Communication System consists of three major subsystems which have the following functions:

a. GOSS Termination Subsystem

(1) Terminates the high speed data (HSD), low speed data (LSD), and teletype circuits which connect the remote elements of GOSS and other outside support agencies to the IMCC

(2) Terminates the part-time video circuits between Cape Canaveral and the IMCC

(3) Terminates and switches the full-time and part-time, leased voice circuits from the remote elements of GOSS, and from other outside support agencies

(4) Provides technical control facilities, through which all GOSS communication circuits pass so that quality monitoring of the circuits can be performed and control of circuit routing and terminal equipments provided. Coordination with the AT&T long lines test facilities can be effected by this facility through GSFC.

(5) Provides operational control and supervision over the GOSS network during mission periods and coordination with other agencies for relinquishing of this control during non-mission periods.

b. Communication Processing and Control Subsystem

(1) Provides electronic switching and control of traffic from the GOSS network and other circuit terminations for proper routing of alpha-numeric text and digital data messages to the IMCC and MSC destinations during both mission and nonmission periods.

(2) Provides all internal communication facilities for both network and internal IMCC traffic, including routing and distribution of communication flow and messages

(3) Provides liaison between the Communication Director and both the Network Status Monitor console and the Technical Control Facilities.

c. IMCC Internal Communication Subsystem

(1) Provides internal communication circuits, terminal equipments, and technical control facilities for the operational voice intercommunication system between the operational positions within the IMCC

(2) Provides local teletype, courier and facsimile circuits and equipment for the local delivery of the text traffic from the GOSS communication network, via the IMCC Message Center

(3) Provides voice paging and public address facilities.

Figure 3.3-1 is a block diagram showing the overall communication flow within the IMCC. In the following discussion of each of the subsystems, the Communication Processing and Control Subsystem, and the Internal Communication Subsystem are emphasized. Within the GOSS Termination Subsystem, the technical control, voice control switching, and GOSS supervision facilities will be discussed in detail in this report. However, the terminal equipments utilized on the HSD and LSD circuits will be included as part of the GOSS Performance Requirements Specification (WDL-TR-E122) so that the complete GOSS circuits from terminal to terminal including data modems, and error control techniques can be discussed in one report to provide continuity of discussion without excessive referencing between the two documents.

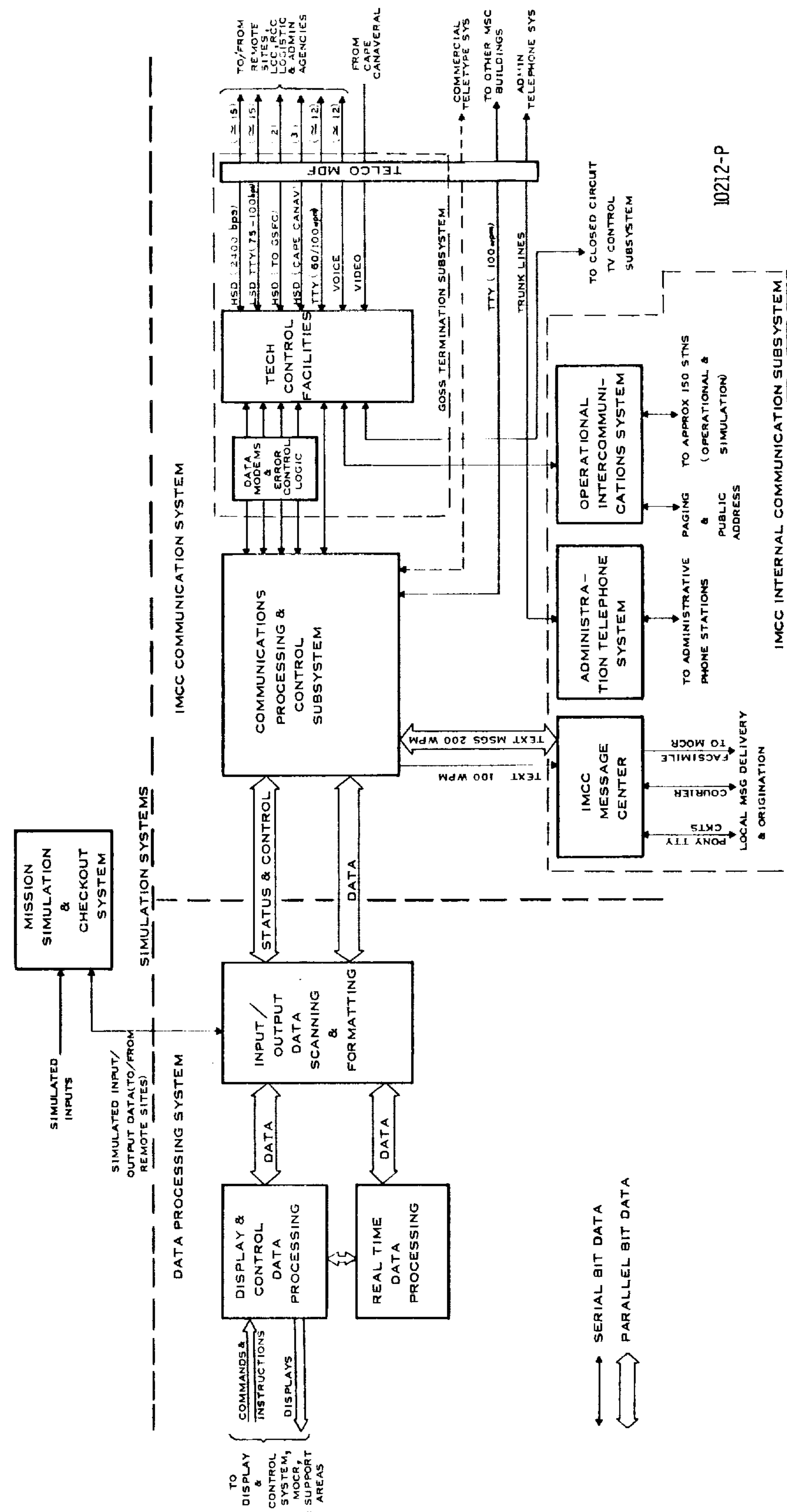

Figure 3.3-1 Overall Communications Flow Within IMCC

3.3.1 GOSS Termination Subsystem

The GOSS Termination Subsystem comprises the terminal equipment, control and test facilities on all high speed and low speed data circuits, teletype, voice and video circuits which come into the IMCC Communication System from the remote elements of the GOSS network. The majority of these equipments are located in the Communication Control Room and the Data Terminal Equipment Room.

3.3.1.1 Technical Control Facilities

All circuits entering or leaving the IMCC pass through the Technical Control facilities in the Communication Control Room so that this is appropriately the control center for the entire IMCC-GOSS communication network operation. By means of the monitoring and test facilities provided, the status and quality of all circuits can be determined. Through the use of extensive patching facilities, circuits can be rerouted to handle all conditions of traffic loading, and circuit or equipment outages.

The operational activities of Technical Control are divided into three functions; (1) traffic routing, (2) quality monitoring, and (3) maintenance. The equipment in the Communication Control Room should be grouped according to function, and the groups arranged in such a manner as to provide the optimum in operational efficiency. Figure 3.3.1.1-1 is an artist's conception of a typical technical control area. The traffic patching facility, which includes the traffic patching bays and the monitor teletypewriter consoles, appears on the right. In the center, occupying a position readily accessible to both traffic patching operations and maintenance patching operations, is the quality monitoring facility. On the left is situated the maintenance patching facility including the equipment patching bay lineup to the right, the audio patching bay lineup to the left, and the audio test bay located between the two lineups.

The traffic patching bays include equipment by which the operator

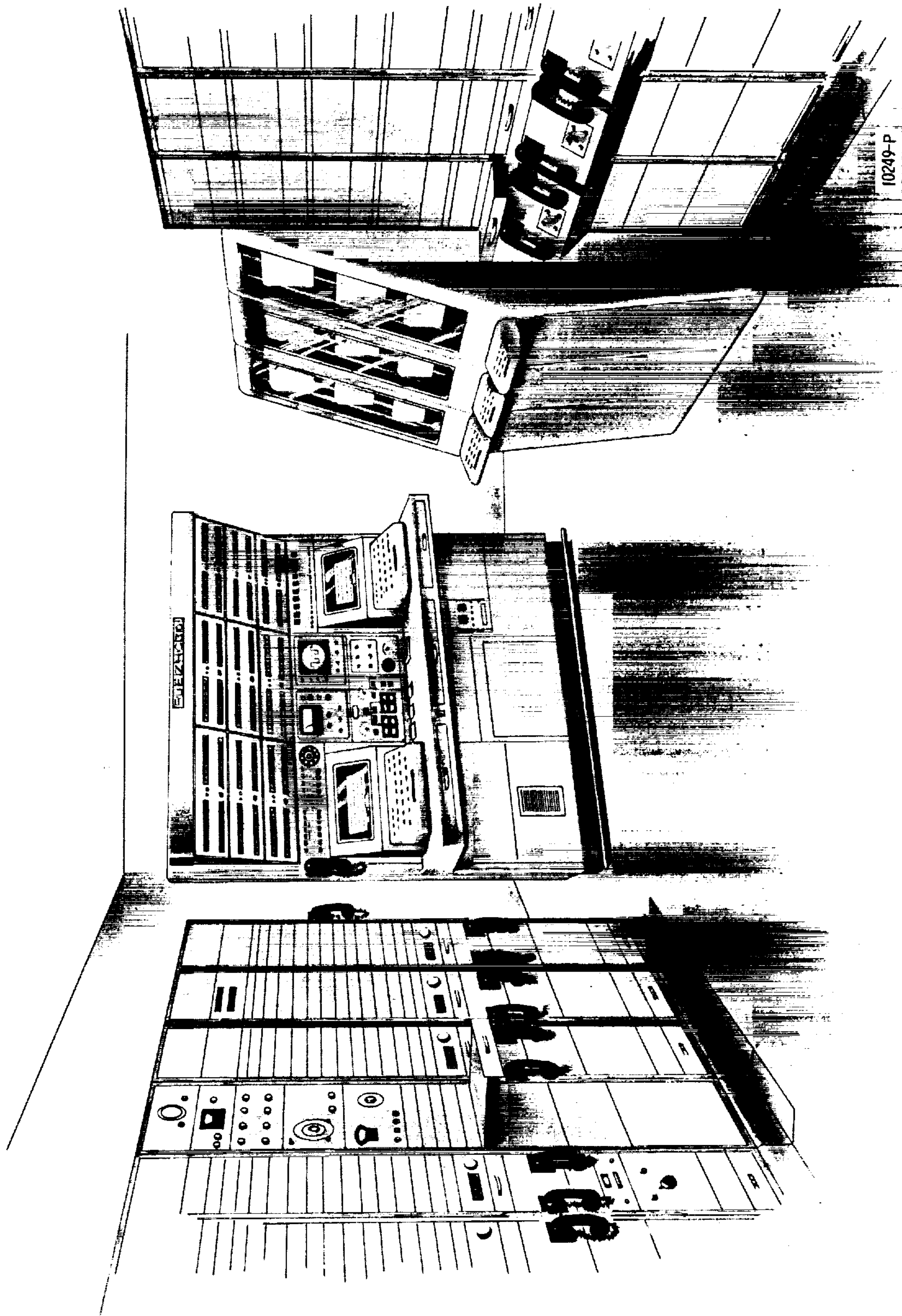

Figure 3.3.1.1-1 Artist's Sketch of Typical Technical Control Area

reroutes teletype and digital data traffic to provide on-call system service to circuit users and access for high impedance monitoring on either send or receive teletype circuits. The electrical design of this bay should be directed to its primary function of providing the facilities required by the operator for monitoring and controlling all traffic between; (1) the GOSS network and the communication processor, and (2) the communication processor and the IMCC Message Center and other teletype terminal locations within the MSC complex. Associated with the traffic patching facility are the monitor teletypewriter consoles. These consoles can be provided with space for mounting up to three sound-proof monitor teletype page printers, and equipped with shunt monitor applique units which provide the capability for high-impedance, bridged monitoring of an operating teletype circuit with no degradation of the low-impedance teletypewriter loop circuit.

The quality monitoring facility consists of a quality monitor console. This console should contain the necessary equipment to enable operators to monitor and to perform qualitative analysis of the teletype and data circuits prior to their entry into the communication processor.

For those channels equipped with on-line monitors, automatic and continuous monitoring of the channel status is presented by the on-line monitor indicators spread across the top portion of the front panel. The operation of the console can be both simple and efficient by the use of a punched card selection technique to call up a particular circuit for detailed analysis. In addition, the on-line monitors which will permanently monitor each line on a high impedance bridging basis should provide the following indications to the operator to identify faulty circuits;

a. Visual and audible indications when the signal quality drops below the level which has been preset on the monitor

b. Advisory information on the absence of traffic or an open-circuit condition on the monitored circuit

c. An alarm indication when the number of hits on a line exceeds a preset number in a given three minute period.

Other functions and equipments at this quality monitoring console should include:

a. Telephone and teletype order wire equipment
b. IMCC operational intercommunication keyset
c. Alarm indicator panel for equipments of interest to the quality monitor operator
d. Operator's test equipments including digital distortion analyzers, oscilloscopes, level meters, test transmitter-distributor, random word bit generators, etc.
e. Channel status indicators
f. Cardmatic switch and switch circuitry designed to automatically preset the test and monitor instruments for the selected channel. Card storage and facilities for making up new or replacement cards should be provided.

The equipments included in the console permit rapid diagnosis of channel troubles and provide the operator with ample communication facilities to keep him informed of equipment status and maintenance progress.

The maintenance patching facility permits the analysis of DC and audio frequency channels for the purpose of determining which links in the system are not operating properly. Once this determination has been made, a link known to be in proper operating condition may be substituted for a faulty link, thereby allowing the channel to continue to operate with a minimum loss of time while more extensive testing and repairs are being made on faulty equipments.

The maintenance patching facility will consist of three major components:

a. Audio Test Bay

The audio test bay shall provide a central location for test instruments used to perform routine testing and evaluation of audio frequency lines and/or intersite channels. It also provides a means for connecting test equipment to operating channels.

b. Audio Patching Bay

The audio patching bay provides facilities required for patching between audio channels and/or audio terminal equipments for control and maintenance purposes. The bay also provides the means for monitoring all incoming and outgoing audio channels and connecting audio test equipment to any audio line or channel.

c. Equipment Patching Bay

This bay provides the means for substituting various equipments for the purpose of maintenance and repair.

Figure 3.3.1.1-2 is a functional block diagram of a typical technical control facility which shows how it would be integrated into the IMCC/ GOSS Communication System.

3.3.1.2 Teletype

Initially, a majority of the present Mercury teletype circuits utilizing Baudot code transmissions may be used from the remote elements of the GOSS network during both mission and non-mission periods. In addition, direct teletype circuits from Goddard, Cape Canaveral and other outside support agencies will enter the IMCC Communication System. These circuits will operate at both 60 and 100 wpm. The 100 wpm circuits will be used primarily within the continental United States.

Eventually, the intent is to convert the GOSS network teletype circuits to low speed data circuits during IMCC mission periods, operating over the same teletype bandwidth channel facilities. The primary advantage of this type of operation is the utilization of more efficient coding than the present Baudot code, and the use of more efficient error control techniques to insure the maximum reliability of data. This conversion of teletype to low speed data (at 75-100 bps) will be a gradual transition during the early Gemini rendezvous missions. Because of the flexibility of the communication processor (using electronic switching and code conversion techniques), this phase-over period will not introduce any significant problems or modifications within the IMCC. A more detailed discussion of the GOSS teletype network and terminal requirements, as well as new circuit requirements for the GOSS

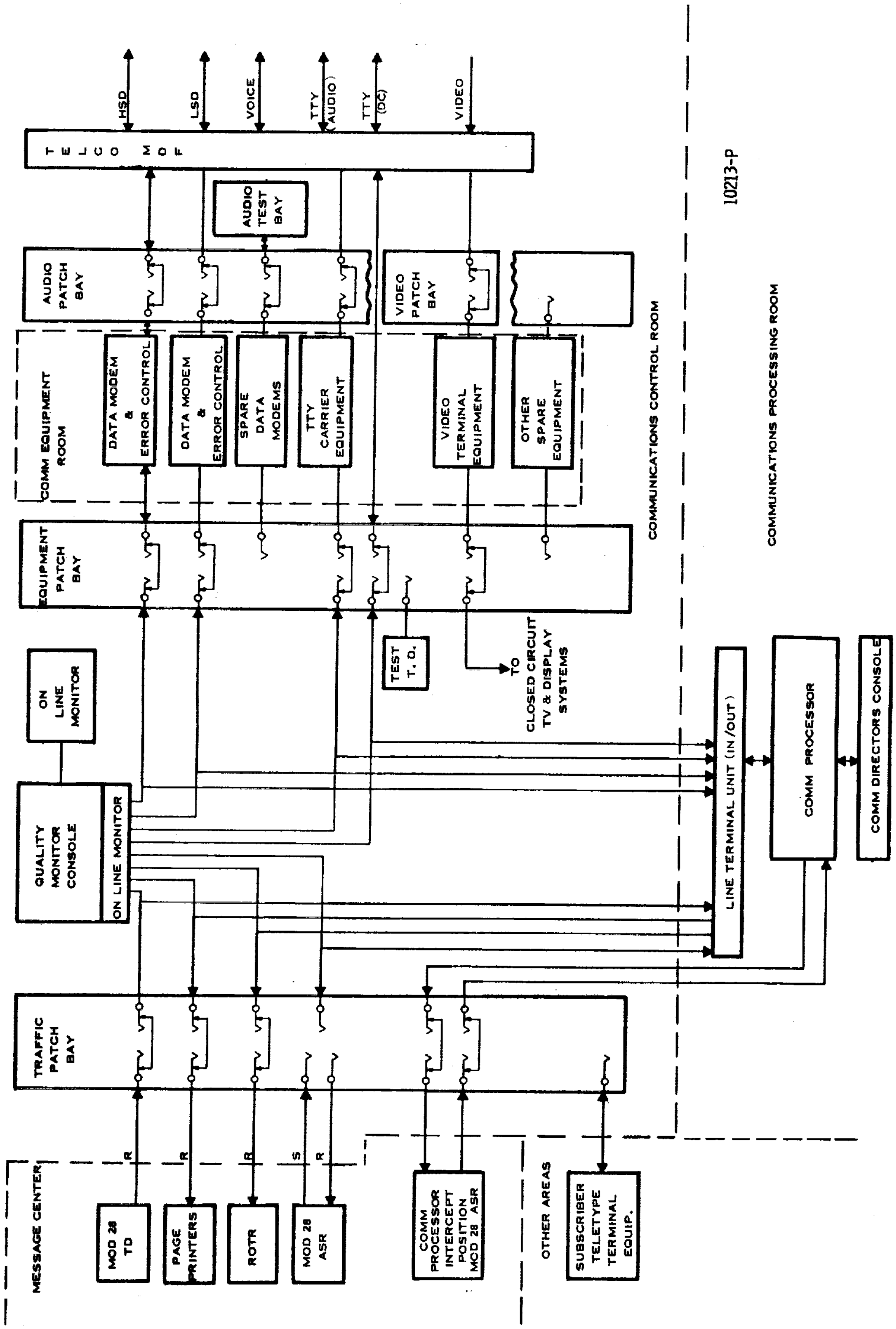

Figure 3.3.1.1-2 Functional Block Diagram of Technical Control Facilities

network will be found in the report on GOSS Performance Requirements Specification (WDL-TR-E122).

Additional teletype circuits from outside agencies and support areas will include the following:

a. Weather network terminations, including facsimile
b. Military Recovery Communication network
c. Liaison Military and DOD circuits
d. Commercial Western Union teletype and Bell System TWX circuits.

These circuits, with the exception of item d, may also come under the cognizance of technical control personnel before terminating in their areas of concern.

3.3.1.3 Low Speed Data

The low speed data circuits terminating at the IMCC will be, in part, new circuits required to meet the greater mission requirements in addition to those circuits resulting from the transition of Baudot code to digital coding over the present Mercury teletype bandwidth facilities. Data bit rates will be approximately 75 to 100 bps (corresponding to 100 wpm Baudot code transmissions). Actual data rates will be determined at a later date.

These data circuits will carry both compressed raw data formatted for use by the IMCC computation subsystems, and alphanumeric text messages in digital format which will be code-converted and routed to the IMCC Message Center. The Communication Processor will perform this function.

3.3.1.4 High Speed Data

All remote elements of the GOSS network which utilize adequate hardwire transmission media over the complete route to the IMCC will be provided with facilities for high speed data transmission (at 1200/2400 bps) over nominal 3 kc voice bandwidth circuits. These circuits, many of which are common to more than one overseas station, may revert during non-mission periods to shared frequency-multiplexed teletype carrier transmission in Baudot code. The Baudot-coded message formats will be compatible with the existing Western Electric Type 83B2 electro-mechanical teletype switching center at GSFC.

The serial bit stream data arriving at the IMCC will be quality monitored at the Technical Control facilities and then the raw data and alphanumeric text messages will be segregated and routed to the IMCC Computation Subsystems and the IMCC Message Center, respectively, by the Communication Processor.

3.3.1.5 Voice

Voice circuits to all remote sites and support functions are required. While it is essential that certain information, such as tracking data, command instructions, and telemetry data be sent by record messages for subsequent processing and evaluation, voice transmission is superior for the transmission of urgent advisory information, reports of conditions, etc. In addition, the voice circuits permit the Flight Director at the IMCC to have direct voice communication with the spacecraft crew.

Terminal facilities for a number of leased voice circuits will be required at the IMCC. These voice circuits are full period leased 4-wire circuits. Approximately 10 of these lines may be diversely routed to the Goddard Switching, Conferencing and Monitoring Arrangement (SCAMA) voice control facility, where patching and conferencing of circuits from the remote elements of the GOSS network will take place. During mission periods, the GSFC voice switching facility will be under the direct operational control of the Communication Director at the IMCC. During non-mission periods, this voice network is used for non-mission support under the direction of Goddard.

Circuit assignments will vary but will be used similarly to the existing leased voice circuits used for the Mercury Project. Additional requirements will be detailed in a later revision of this report. The primary voice circuit which ties together all elements of the GOSS network will have a call-up capability for a diversely routed standby route during mission periods within the continental United States. Use of this circuit will be governed by the location of the orbiting spacecraft since priority is assigned to the site having the spacecraft in view. All sites may monitor all conversations, at the discretion of the Flight Director. This arrangement will retain the circuit cut-off capabilities at GSFC and certain remote locations (if necessary) for cutting out circuits which become noisy due to propagation difficulties as is common on HF radio circuits.

A voice switchboard facility will be required at the IMCC. Its functions will consist of the following:

a. Quality monitoring of the voice circuits and subsequent liaison with the Technical Control facilities

b. Conferencing of any combination of circuits terminating at the IMCC

c. Programmable patching of fixed networks to integrate with the operational intercommunication system

d. Non-mission assignment of full period lines to hot line telephone set status at specified location

e. Provide a call-intercept position for the administrative telephone system during mission periods (to prevent unauthorized calls in the MOCR and other operational areas)

f. Terminate and switch additional directly-routed leased circuits from Cape Canaveral, DOD and other support areas

g. Coordinate with the Goddard SCAMA Voice Control Center

h. Control of voice recording on critical circuits; this position will be manned only during mission periods.

3.3.1.6 Video

It appears desirable to provide the IMCC with the capability to visually communicate with the Launch Complex at Cape Canaveral concerning pre-launch and launch activities. A television transmission channel may be leased or implemented to transmit such video information between the Launch Complex and the IMCC where it would be entered into the television distribution system for viewing at any television display device. The feasibility of providing a two way full duplex video conference circuit is under study and firm recommendations will be made at a later date.

Within the IMCC, the common carrier will terminate this video channel (4.0 to 6.0 Mc bandwidth) with an A2A Termination Set located in the common carrier equipment room. This termination set is equipped with two 75 ohm coaxial output terminations, a Program Output and Monitor Output. The Program Output will be routed directly to the closed-circuit television termination equipment which will distribute the video information to the appropriate displays. The Monitor Output jack will feed this same video information to monitor equipment within the Technical Control facilities where quality monitoring of the circuit can be performed, and proper liaison with the Telco Liaison representative can be effected.

3.3.2 Communication Processing and Control Subsystem

3.3.2.1 General

The installation of an automatic, high speed, electronic message switching and processing center terminating the teletype and data circuits of the GOSS communication network is proposed. This communication processing and control subsystem will serve as the nerve center for the IMCC external communication requirements.

The primary functional requirement of this facility is that of accepting traffic from the worldwide GOSS network, either direct during IMCC mission periods or via Goddard during non-mission periods, and separating and routing this traffic (both serial bit stream data and text messages in Baudot or digital coding) to the appropriate destination within the IMCC. A similar requirement exists for assembling and routing of all outward communication from the IMCC. Therefore, a definite requirement exists for a communication terminal switching center at the IMCC, over and above the switching center requirements for all NASA circuits at GSFC.

Future plans for GSFC include the implementation of an automatic, electronic switching center replacing the present electro-mechanical Mercury and Spacon systems. By proper engineering coordination and the use of compatible systems, the overall communication operations and procedures will be enhanced and interface problems minimized.

This communication system at the IMCC will be monitored and controlled by a multiplexed, stored program digital computer, henceforth referred to as the communication processor. Peripheral units can be added to the processor depending upon the present and future requirements at the IMCC. Peripheral equipment for the communication processor includes input and output line terminal and control units; a random access storage file to extend the processor's memory for buffer storage of messages; magnetic tape units to provide historical files, traffic analysis and message accounting; a supervisory control console; and a message intercept position for garbled messages.

3.3.2.2 Overall Criteria

The multiplexing of multiple input lines with multiple output lines is a basic principle of switching in point-to-point communication. For the switching function to be efficient, it must be fast enough to connect the traffic on each incoming line to the desired outgoing line, with little or no delay, except in the outgoing queue necessary for store and forward operation. The burden of moving traffic is transferred to the outgoing line. This means that the switching system must accept and unload all traffic from all the incoming lines connecting to it. Storage of waiting traffic is the primary problem in any switching center.

The use of computer techniques of stored program control to make message switching and processing operations automatic eliminates the cross-office delay and the inflexibility and inefficiency common to the electro-mechanical switching centers in wide use today.

In designing an electronic communication switching and processing system, the communication problem must be approached directly. The selection of the computer which will serve as the communication processor should be functionally directed towards the existing communication problems and requirements. Most existing computers have limitations in data input-output and transfer, and have an arbitrary list of instructions emphasizing arithmetic and logic operations .... not communication functions. Conventional computers are fixed for data processing whereas they must be flexible for data communications.

To design and specify an efficient communication switching center for the IMCC, it is necessary to take a close look at the requirements and functions which must be accommodated. These are covered in the following sections and, as further traffic analysis and loading studies for the IMCC operations are completed, will be modified and discussed in more detail in future revisions of this document.

a. Switching Requirements

1. Number of circuits: Present planning indicates there will be a total of approximately 40 input/output lines from the communication processor. These lines will consist of high speed data, low speed data and teletype information. Actual line requirements are not firm at this date. Therefore, it seems reasonable to recommend that the initial system specified for the IMCC be designed for a maximum of 100 lines, and equipped for a total of 50 lines, assigned as follows; 15 high speed data (HSD), 15 low speed data (LSD) and 20 teletype (TTY) lines.

2. The communication processor must switch rapidly enough to accept all incoming messages. In other words, it must be capable of handling the estimated peak traffic loading expected on all internal IMCC and external GOSS communication lines.

3. The communication processor must be time shared among all incoming and outgoing lines.

4. The communication processor must sample each incoming line, determine message precedence, perform address recognition, and provide flexible and automatic routing of all messages within the IMCC.

5. The requirement for switching between external lines (i.e., remote site-to-site communication via GOSS) will be limited, but this capability should be provided.

6. Each outgoing line must be sampled to determine its status as defined by the following states.

   (a) Inoperative

   (b) In use- transmitting high precedence message

   (c) In use- transmitting low precedence message

   (d) Not in use.

7. Outgoing messages must be queued according to precedence, and any message can be interrupted for no delay priority traffic.

8. Multiple address messages, ranging from two addresses to an all stations broadcast, can be accommodated at any time.

9. Data on the HSD/LSD lines must be separated and routed

to the computation data busses and/or the Message Center by recognition of address 'tags' in the data stream.

10. Data and digitally coded alphanumeric text messages must be interlaced and transmitted to common addresses via the HSD/LSD lines.

11. Automatic speed conversion between data rates of 75 to 2400 bps must be accomplished.

12. Code conversion must be performed (i. e., digital to Baudot and vice versa). The processor must be capable of accepting, storing, and retransmitting messages of dissimilar form between certain unlike terminal devices.

13. The processor must provide automatic diversion of overflow traffic to random access storage files, and timely return for retransmission.

14. Automatic detection of internal errors by generation and checking of parity must be accomplished.

b. Bookkeeping Requirements

To continually monitor the status of all messages handled by the communication processor and also to monitor the status of the processor itself, the processing portion of the switching facility must perform the following bookkeeping functions;

1. Keep a running account of all incoming messages on each line
2. Keep a running account of all outgoing messages on each line
3. Correlate incoming messages with outgoing messages
4. Direct all accounting data to the proper storage areas.

The communication processor will automatically insert on each incoming and outgoing message an identification consisting of letters and numbers identifying the circuit and the particular transmission. All such identifications, with date-time entries, are logged on magnetic tape. Provision may be made for the interrogation of this tape and for printing out by means of a high-speed line printer. Automatic message accounting by the processor prevents lost messages and provides data for subsequent traffic analysis.

c. Man-Machine Interface Problems

Because the system is under the direct supervision of man, a direct interface between man and machine is required. Therefore, the processor must:

1. Indicate to the operating personnel the status of each incoming and outgoing line

2. Indicate the status of all bookkeeping functions
3. Indicate the presence of exceptions to normal operation (garbled headings, out of sequence messages, etc.)
4. Provide facilities for program maintenance and control, fault reporting and manual override.

d. Storage Requirements

The outgoing lines accept traffic from all incoming lines. This may cause queues to form; therefore, outgoing lines have some storage capability. In addition, some storage is required on the incoming lines to accomplish speed and code conversion.

1. Incoming Line Storage

   Speed conversion is necessary to match incoming speed with the communication processor speed. Since the incoming line speeds are fixed, speed conversion can be accomplished only by an incoming line store in which the slow input line accumulates data until enough is stored for the communication processor to take the data at its own rate. The amount of storage needed depends on several factors:

   (a) The sampling rate of the processor
   (b) The number of lines to be sampled
   (c) The speed of data transfer
   (d) The method of processing the data.

2. Outgoing Line Storage

   Implicit in all storage operations is message retrieval. Basically, there are two different methods which can be used. In one method, separate discrete storage for high and low precedence messages is provided on each outgoing line so that the messages have access to this line as the line becomes available. This eliminates the need for further processing during information retrieval, and is the most direct and simple method of handling the switching problem. Because a very large part of the potential storage is in a waiting stage, rather than being used, the storage utilization is very inefficient. Since storage is expensive, a more efficient storage approach is indicated.

   It is possible to lessen the amount of storage required by assigning a common storage area to all outgoing lines. This can be done in the following manner.

   (a) Each incoming message is sensed and processed.

(b) Once processed, the message is removed from the incoming line to make room for subsequent messages.

(c) The message is put into common storage.

(d) The message in common store either (1) retains all its routing information while in storage, or (2) is reprocessed each time it is taken out of storage.

(e) The processor continually samples both the status of the outgoing lines and the messages in storage awaiting transmission. Each time a match is made between message store and outgoing line, a message is released for transmission.

This approach uses the storage more efficiently and shares it among all outgoing lines. The switching burden is transferred to the processor which time shares all processing and storage functions with incoming and outgoing lines. Since the processor speed is far in excess of the combined speed of all incoming and outgoing lines, the burden placed on it is well within its capability.

3.3.2.3 System Functional Criteria

In fulfilling the above general requirements, and also the more detailed implicit requirements, definite functional criteria must be established and met.

a. Compatibility

The Communication Processing and Control Subsystem is to be one element in a large existing and operating worldwide communication complex. It must, therefore, be designed to fit the existing system rather than having the present system conform to specifications established by it. However, designing the IMCC communication center for compatibility with the existing GOSS network should not detract from its primary function.

b. Capability

The Communication Processing and Control Subsystem must have the capacity and speed to accomplish the routing, storage, and sequencing for the full complement of communication lines required. It must minimize all queues, other than the outgoing line queues. In addition, it must perform all the bookkeeping and other ancillary functions needed to operate an efficient, coordinated communication center.

c. Adaptability

Because of the dynamic nature of the communication field, any system must be designed to adapt to future changes. If this adaptability is not designed into the system, the system will soon be obsolete. This is one reason that both the software and hardware must be constructed using a building block approach. This will allow modular expansion changes as they are required. The processor can be adapted to changing day to day requirements through simple program changes.

d. Reliability

Two aspects of reliability must be considered, functional reliability and component reliability:

1. Functional Reliability

The primary function of a switching system is to accept all incoming messages and transfer them to the proper outgoing lines. This must be done without losing any messages.

2. Component Reliability

All equipment components must be designed to satisfy the highest standards of reliability. Furthermore, redundant equipment for prime circuits will be necessary to provide continuity of operation during scheduled preventive maintenance and, additionally, to forestall catastrophic failure.

e. Human Factors

Though the switching complex will be completely automatic, there will be areas in which operating personnel must interface with functional procedures as well as with operating equipment. The type of interface designed will be a compromise between man's physical and psychological capabilities, and the cost and complexity of procedures and equipment. The individual must not be taxed beyond his capabilities, nor should the equipment cost or complexity become excessive in an effort to oversimplify tasks best performed by man.

f. Practicality

Since the system will be functioning twenty-four hours a day, seven days a week, it must be designed using sound engineering principles for efficient operation and maintainability, and be practical in cost.

3.3.2.4 Overall Configuration and Major Subsystem Elements

The Communication Processing and Control Subsystem may be defined by detailing the interfaces or information flow between its peripheral equipments, other system elements and operating personnel. Figure 3.3.2.4-1 is a functional block diagram of the Communication Processing and Control Subsystem. It shows the various peripheral equipments and indicates their interconnection by either unilateral or bilateral links. Each link may consist of multiwire cabling for handling the control functions to support the information flow.

The following paragraphs describe in greater detail the functions and operations of each equipment.

a. Incoming Line Unit (ILU)

The primary function of the incoming line unit is the coupling of the input data line to the communication processor. The

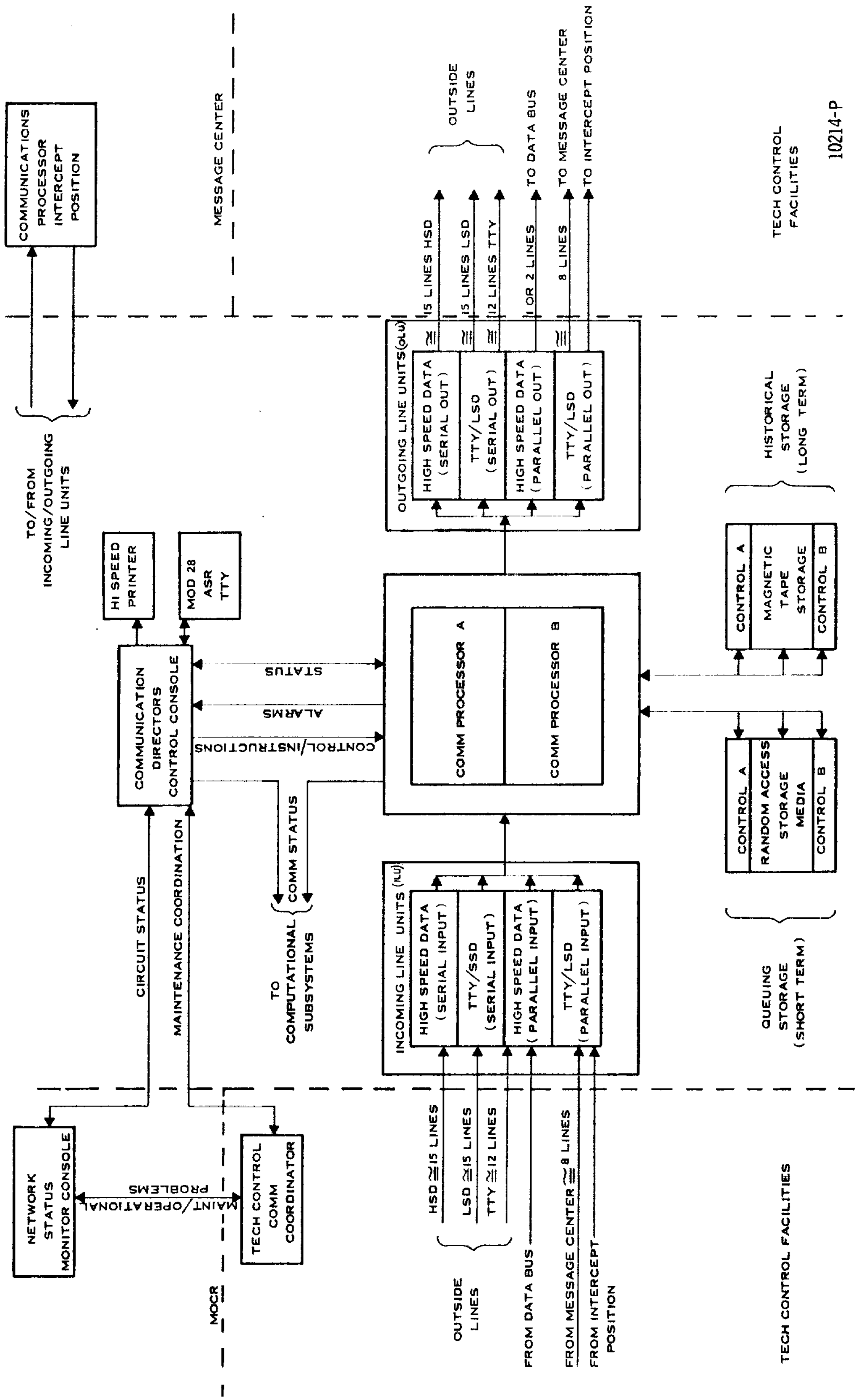

Figure 3.3.2.4-1 Functional Block Diagram of the Communications Processing and Control Subsystem

various input lines operate asynchronously with respect to the communication processor, at speeds of 75 to 2400 bps. The input line units provide the necessary line isolation and speed buffering.

The ILUs receive the incoming data, sample the signal elements, and decide whether they are mark or space. Start and stop elements of the teletype data are stripped, and only the five information elements are retained for storage. When a character (or group of characters) is completed, a ready signal is given the processor which then initiates the transfer of the character(s) into the processor for storage.

In addition to start/stop operation, the ILU can operate with binary stream information. It recognizes the binary stream tag or prosign, and transfers this continuous data stream into the processor, a specified number of bits at a time.

b. Outgoing Line Unit (OLU)

The outgoing line unit receives data from the communication processor output memory at processor memory speed in five-bit characters. Each character is transmitted by the OLU at the required line data rate, with start and stop elements added, where required. The OLU signals the communication processor when it is ready to receive new data.

The incoming and outgoing line units will be housed in standard 19-inch relay racks.

c. Communication Processor (Dual)

The communication processor communicates with both the incoming line units and the outgoing line units. One hundred (100) of each type line unit, each capable of communicating asynchronously with the communication processor may be used in the system. Initially, the system will be equipped with approximately fifty (50) of each type.

Information transfer takes place via memory stores and communication access storage media which store the incoming data until it is ready for processing. The information is processed and sent to an outgoing line if one is available, or to intermediate storage if one is not available. A complete record of incoming and outgoing messages is kept. Queueing of lines is handled so that high precedence messages receive first consideration.

In this application where continuous service is required, high system availability necessitates the use of dual units. The processors will operate independently and concurrently. Both receive common inputs from all lines and process the message to the output register but only one processor transmits to an outgoing line. Operation is transferred from the primary to the secondary processor through the operational console, whenever a malfunction is indicated or preventive maintenance is scheduled. Program control assures no loss of messages during the transfer interval.

d. Short Term Storage Media

A disc or drum storage unit, which provides fast, random access storage for the communication processor and acts as an extension of the processor's main memory for storage of "in-transit" messages, will be provided.

e. Long Term Storage Media

Magnetic tape units are provided to maintain a complete record of all traffic entering the system. These units permit complete records to be kept in any code and format for message accounting and traffic analysis. Tape units also provide historical files. Upon receipt of an inquiry from the supervisor, the communication processor can search the long-term file, locate the message and process it as instructed.

f. Intercept Position

The intercept position or console, located in the Message Center, corrects messages rejected by the communication processor so that they can reenter the communication system. When a message is sent to the intercept position, it is specifically addressed to this position, just as is done for an outgoing message. The message is received at the intercept position as a page copy and also punched on a receiving perforator. The intercept operator makes the necessary corrections, and puts the corrected message tape on a transmitting distributor which is connected back through the communication processor by means of an incoming line unit. The number of intercept positions can be increased as needed. If an intercepted message is uncorrectable, proper service messages to the originating station can be initiated from this position.

g. Communication Control Console

This console serves as the monitor and control center for system operation, providing message and circuit supervision, system control, and output printing. It consists of teletypewriter units, display lamps for line and equipment status, and alarms. From the console, an operator can perform the following functions; send and receive messages, "busy out" non-operating stations, and initiate inquiries to the processor or retrieve messages from file. The processor should print out through the console, automatically or upon demand, the status of all stations. From this console, the communication director effects proper coordination and liaison between the technical control facilities for maintenance and the communication network status monitor console during mission periods.

3.3.3 IMCC Internal Communication Subsystem

Within the IMCC, internal communication will play a major role. Efficient and reliable communication is not only directly related to successful monitoring and completion of manned space flight missions, but also to non-mission operations for normal day-to-day flow of administrative, logistic and support communication required both within the IMCC/MSC complex and between NASA support agencies.

The equipment associated with the IMCC Internal Communication Subsystem is located in two major areas, the Message Center, and the Communication Equipment Room. A detailed discussion of each system requirement follows.

3.3.3.1 IMCC Message Center

The Message Center is the termination point for all text-type traffic arriving at the IMCC from the GOSS communication network, other direct teletype lines from support areas, and via the local teletype circuits from subscriber terminal locations within the MSC complex. The major flow of traffic will be betwe en the communication processor and the Message Center. The communication processor accepts and separates text from data on the data lines, performs digital to Baudot code conversions, and routes all text messages to the IMCC Message Center. These messages, in Baudot code format will terminate on the latest model high speed teletype equipment, arranged for either full duplex or simplex service. Overall communication system traffic loading and information flow analysis at a later date will determine the number of terminal teletype equipments required to assure that message queueing is held to a minimum in the communication processor.

Ideally, high speed digital printers could be used for text traffic arriving on the digital data communication circuits. Because these circuits may also be used for teletype Baudot code transmissions, and because there will always be a large number of strictly teletype circuits, it would be uneconomical to provide both types of terminal equipments within the

Message Center. Therefore, all traffic for the Message Center will be transferred from the communication processor in Baudot code format. This will also alleviate the interface problems between the Message Center and the internal, commercial and direct-line teletype circuits.

Actual message transfer speeds between the communication processor and the Message Center terminal equipments should be at 200-600 wpm on a parellel-bit basis, wherever possible. Present teletype transmit-distributor, tape reader and reperforator equipment can be arranged for this speed of operation. Recent developments of line-at-a-time teleprinters may make it feasible to transfer messages for page copy at speeds of 200-600 wpm. This fast transfer of messages will result in a reduction of terminal equipment requirements.

It is presently planned that all teletype pony circuits between the IMCC and the MSC complex be terminated in the Message Center. These circuits should be operated at 100 wpm speed for rapid clearance of traffic between terminals.

Further study will be required before a final recommendation can be made as to the advisability of providing receive-only typing reperforator tape copy of all messages arriving at the Message Center or whether long term record storage by means of magnetic tape units associated with the communication processor will be sufficient.

If the magnetic tape units provided with the communication processor are used for long term (2-3 months) historical storage of all message received, a minor revision to the present teletype network leader formatting procedures will be required. Tape copy of all messages delivered to the Message Center for retransmission via the individual pony and/or direct teletype circuits will be required. Therefore, two types of trunk circuits will be required from the communication processor; one type would terminate directly into multi-copy page printers for local IMCC deliver, the other type would terminate page printers and associated typing reperforators. These would provide a tape copy for manual insertion in the transmitter-distributors associated with each outgoing circuit. This system would require additional tags (or prosigns) in the message headers so that the communication processor could distinguish between the two types of traffic for the Message Center. The alternative to this system would be to provide tape and page copy of all traffic received in the Message Center, with no changes in the present formatting procedures required.

Thought was also given to allowing the communication processor to automatically route messages on the various pony circuits, as well as to the Message Center. These pony circuits would then terminate at the line terminating units of the communication processor. However, this would require automatic addressee recognition and routing, and a complete revision of present formatting procedures. Because of operator training problems, possible lack of individual addressee information at the message origination terminal, and, as is often the case, week-to-week changes in pony circuit requirements, this method is not recommended.

The Message Center would also contain a number of high speed transmit-distributor equipments for outgoing traffic, keyboard send/receive units, and tape punches for order wire and conferencing arrangements as well as for tape preparation of outgoing messages. Maximum use of the Teletype Corporation's new 600 wpm tape transmitters and punches for entry of traffic into and from the communication processor is recommended.

The intercept position associated with the communication processor would be located in the Message Center. This position would print out all text traffic which is garbled, or mutilated in such a way that the communication processor does not know what to do with it except to send it out to an intercept position for human intervention. Here, the operator can correct obvious address or format garbles and return the message to the communication processor for routing or originate service messages on the mutilated traffic.

Automation of the Message Center teletype equipments, their functions, and delivery of traffic to local addressess will decrease the message handling time periods, reduce the physical workload and manpower requirements. It would also consolidate equipments and operational areas. The teletype facilities within the Message Center should be automated consistent with the present state-of-the-art and the IMCC traffic requirements.

In the future, as both the operational and administrative traffic volume and circuits increase, the flexibility of the communication processor, with proper programming, could provide completely automated local message delivery to the subscriber terminals and eliminate a majority of the present Message Center functions. Of course, this would also require complete revision of the existing message format requirements.

As in any communication system, the major communication delay times are at the terminal locations and are a result of local message delivery and origination procedures. Three separate and distinct methods of internal message delivery of traffic arriving at the IMCC Message Center are contemplated. These are as follows:

a. <u>Subscriber Access Teletype terminals</u>
These would consist of local teletype pony circuits to other buildings within the MSC complex and possibly to the Administration and Support Wing of the IMCC building. All traffic during both non-mission and mission periods of addressees served by these subscriber access terminals would be routed via the pony circuits with local message courier service used from the subscriber access terminals to the individual addressees.

b. <u>Message Courier</u>
Within the IMCC Mission Operations Wing, all administrative, logistic, and operational messages would be delivered via the normal inter-office mail courier service. Other methods, such as pneumatic tube or conveyor belt delivery, are not recommended because of facility design problems and inherent operational drawbacks associated with these systems. Message pickup windows are provided at the Message Center.

c. Facsimile

During mission periods, it is contemplated that a system similar to the Western Union "Speed-O-Fax" service could be used for all critical traffic to the MOCR (and to other areas as may be deemed necessary). It has several advantageous features over teletype pony circuits and message courier delivery;

Advantages

1. Terminal receiving units are very small
2. Noiseless operation
3. Speed of delivery essentially the same as teletype 100 wpm operation (depends on message length)
4. Would eliminate courier foot traffic in and out of the MOCR

Several minor disadvantages should be pointed out. These could be overcome through operational procedures and training;

Disadvantages

1. The receive units must always be equipped with new paper upon receipt of messages
2. Long messages must be paginated since the total message length is limited by the receiving drum circumference
3. Delivery of the message to the cognizant person within the MOCR must still be effected
4. Only one page copy would be available at the terminal end

Further study of these problems and requirements as well as an investigation of present state-of-the-art "noiseless" teleprinters must be accomplished before a final system or method of delivery of operational mission traffic within the MOCR can be recommended.

The implementation of the Message Center should include the following considerations;

a. An adequate storage area should be provided, accessible from within the Message Center for storage of teletype paper, logs, historical tape records and other miscellaneous operating supplies.

b. Limited access to the Message Center to reduce unauthorized entrance and personnel traffic must be provided. This will be accomplished by means of a double entry, which will also serve as the message pickup area

c. Adequate diffused lighting should be installed to eliminate objectional shadowing at all operating positions and to eliminate glare from the operating equipments and page-printer paper.

d. This room should be soundproofed as much as possible.

e. Adequate space should be provided for logging and message servicing areas, and for partitioned office area for the Message Center supervisor.

f. The use of 24-hour clock and time stamps is recommended. Automatic date-time stamping should be provided on receipt of all messages.

g. The use of non-carbon reproducible paper in all teletype page printers is also recommended. This would contribute towards keeping a clean Message Center, and minimize the disposal problem.

3.3.3.2 Operational Voice Intercommunication Subsystem

The voice intercommunication subsystem (hereafter referred to as the intercom subsystem) will be an important and extensive equipment complex in itself. This communication network will provide point-to-point and conference voice communication within the operational area of the IMCC, and will be connected to outside circuits via a standard dial system.

The functional design of the intercom network will be tailored to the organizational and operational structure of the IMCC. The IMCC, and the MOCR, in particular, will be the gathering point of a great amount of information. This would imply that, at each organizational level, operating personnel would assemble the essential information appearing at that level and pass it on to his immediate supervisor. Using this reasoning, the basic intercom nets are considered to be those that connect the positions at each organizational level. An example of a chain of such nets, based on current thinking, is shown in Figure 3.3.3.2-1. For instance, the Assistant Flight Dynamic Officers report to the Flight Dynamic Officer who would integrate this information and report to the Flight Director on a separate net. A useful feature in this system of networks would be the ability of certain positions, such as the Flight Director and the Flight Dynamics Officer, to use two or more

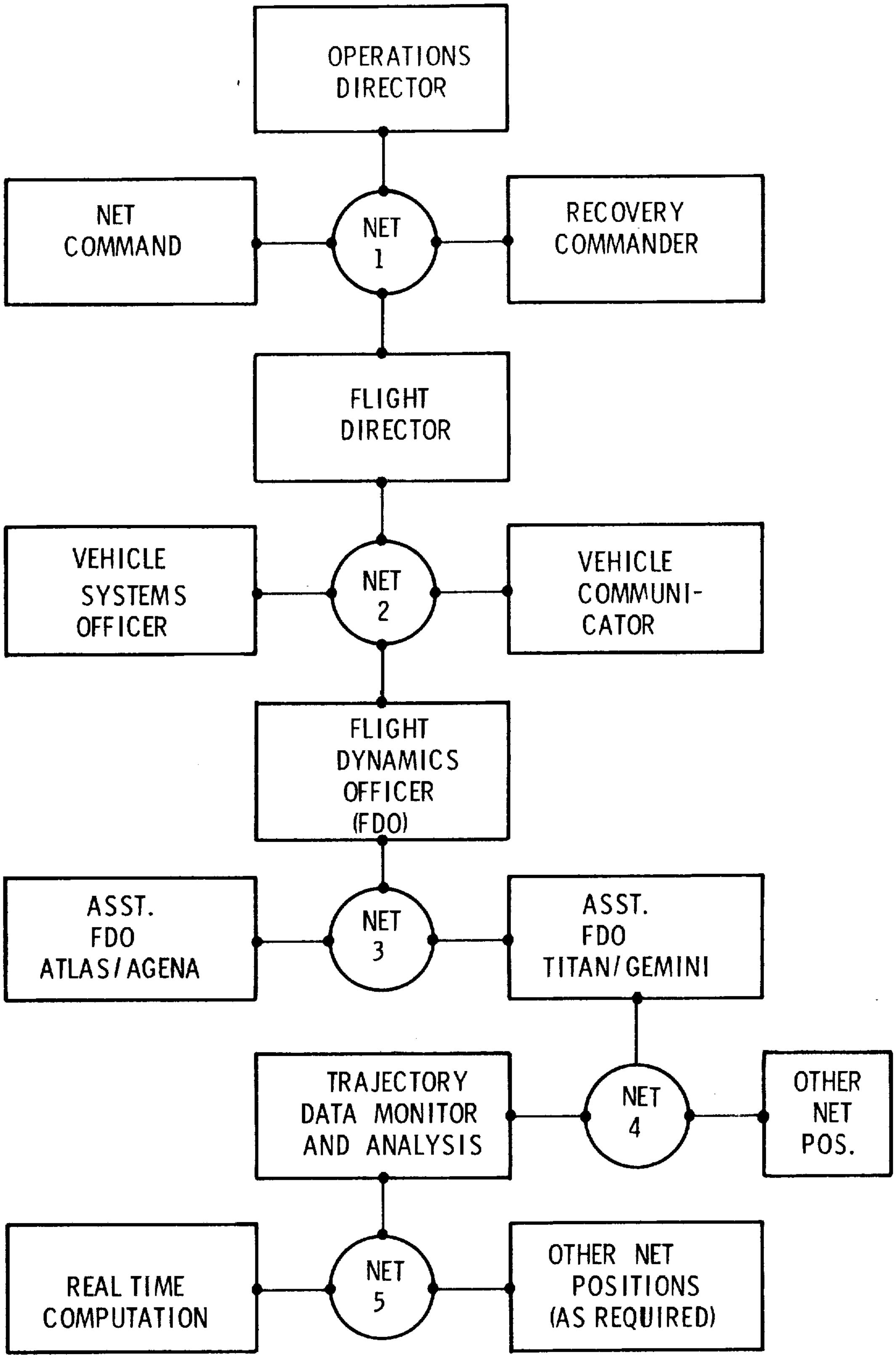

Figure 3.3.3.2-1 Typical Chain of Intercom Nets

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nets at the same time. This scheme would provide more rapid communication while, at the same time, making full use of the connecting operator's special knowledge. Each of these basic nets would be full four-wire circuits and would probably be the principle nets during normal mission times.

In addition to these stratified nets, there would be more inclusive, talk-listen loops, such as a general Flight Director net which would connect all positions reporting to him. Also, the equipment areas are expected to have extensive loop arrangements, both for real-time support of a mission and for off-line maintenance. Loops connecting MOCR personnel to equipment areas would be useful during emergency situations. The complexity of the intercom system means that each network must have its own set of operating rules, priority, ringing, etc. To insure contact between certain positions during critical or contingent periods, a paging net could be provided and/or an override circuit could be installed. In the MOCR, for example, this override feature might be limited to the Operations Director and the Flight Director.

A monitoring system will also be provided. Many of the talk-listen nets appearing on an intercom station will also have an arrangement that will allow any or all of these circuits to be monitored without causing interference. Undoubtedly, some intercom stations will be able only to monitor certain nets.

Due to the uncertainty of network assignments as currently exhibited in the Mercury Control Center and to provide greater flexibility for future programs, several keys from each intercom station will connect that station to a patch panel or cross-bar switch in the equipment room. This patch panel would allow the rapid addition of new networks, or stations to existing nets. These connections could be either standard talk-listen or monitor only. The use of preprogrammed patch panels or crossbar switching would make it possible to set up a new system while the old one was still in use. The wired patch boards could be stored for future use.

A majority of the intercom stations will have a network connection to the local telephone exchange and will be provided with a standard telephone dial. This would provide connection to outside circuits and point-to-point contact within the intercom system. This function would be quite similar to that presently used in the Mercury Control Center.

As in Mercury, all remote sites would be connected to a single loop. All positions in the MOCR would be able to either talk-listen, monitor or both on the remote site network. Because of the proximity of the "local remote site" there will probably be more than one loop connection to the IMCC.

It is expected that roughly 110 intercom stations will be required for the initial IMCC operational systems installation. This number may be broken down as follows;

Area	No. Stations
Single MOCR	15
MOCR Support	23
Equipment Areas	21
Meteorological Center	3
Local Remote Site	10
Total	72
Second MOCR and Support	38
Total	110

Past experience has indicated that key type intercom stations are very satisfactory. Assuming that each of these stations will require approximately one standard relay rack for switching, power supplies, test panels, etc., the intra facility communication equipment room, as now specified, will be sufficient for 180 to 200 individual stations. This estimate includes provisions for an internal technical control facility containing test boards and patch bays, which will be used for rapid adjustment and checkout of the intercom system and equipment. As a rough estimate of intercom station size, it is expected that the most extensive station would have 42 individual keys or push-buttons and a dial, while the least extensive would have about 6 and no dial.

3.3.3.3 Voice Paging and Public Address

Certain intercom stations will have key access to the public address system. The voice paging would, of necessity, be universal; however, the public address function could be divided into several loudspeaker areas so that any area, or combination of areas, may be serviced.

SECTION 4
DATA PROCESSING SYSTEM

4.1 SYSTEMS CONCEPTS

4.1.1 Differences from Mercury Missions

4.1.1.1 Specific Task Changes

a. An operational mission and a simulated mission are to be supported simultaneously.

b. Two vehicles may be involved in each of these missions.

c. Each mission will be more complex since there will be a greater number of specific parts, or phases, involved. In addition, the decision as to which future phases to be implemented will be a function of the past performance of the mission.

d. Many of these new phases will involve lunar travel (Apollo).

4.1.1.2 Differences in Resulting Systems Concepts

Three differences in the basic data processing functions and computation loads result from these new tasks.

a. Much more computation must be done to perform the additional tasks. The simultaneous support of the dual missions involving two vehicles will approximately quadruple the average computing load during the mission. The peak load should not increase by this amount, however, since it is impossible for the high computation load activities to occur simultaneously for all four vehicles. Much more program and data storage will be required since the missions will extend over a much longer time interval, and more different programs will have to be implemented.

b. The addition of more phases to the missions will necessitate the generation of many new types of computer programs. Several of these may be of greater complexity than any of those used in Mercury. Different mathematics will certainly be involved in some cases. Consequently, the overall programming task will be much larger than for Mercury.

c. Since the decision to implement a future phase of any one mission will be dependent upon the performance of that mission up until the decision has to be made, a great deal of flexibility will have to be built into the computer programming. A quick reaction, with no significant interruption in the work output, must result once a phase implementation decision has been made. These differences point out the inadequacies of the present Mercury computational complex and philosophies. Modularity of both data processing equipments and computer programs will be of prime importance in adjusting to varying mission requirements. Program modularity will be a must in order to get the programming task done quickly and properly. Breaking down the overall programming into small sub-programs will allow separate people to do separate parts of the programming task, and these people can be of lower caliber, since they will not necessarily have to understand the overall systems problems. An executive control program will then tie the various sub-programs together in accordance with mission requirements.

The concept of providing 100% backup by having separate data processing facilities running the same set of problems in real time is unfeasible for the Gemini and Apollo programs. The amount of computation required is simply too great to allow complete duplication of the data processing system. The concept of having only a minimal amount of modular equipment backup, which can be assigned anywhere in the system as needed, will provide more effective backup at much lower cost. This is accomplished by having the equipment assigned to the simulated mission available for secondary backup of the operational mission. Thus, several levels of backup are made available rather than one level of backup, which is the case when using 100% redundant, off-line equipment. Since the backup equipment, under this modular concept, will be only switched in as needed, it can be doing additional non-essential off-line tasks, which is not the case when using redundant equipment. These tasks might include non-real time data reduction, new program checking, and real-time monitoring of data and other computer status. Any of these could be immediately terminated when the equipment is needed on line,without degrading any overall system performance.

4.1.2 Major Functions

The primary tasks of the Data Processing System are:

a. To prepare all necessary mission status data for display to the mission control personnel in order to assure successful completion of the mission

b. To provide data processing assistance to IMCC mission control personnel in predicting the future consequences of current mission status and to facilitate the selection of the proper actions to be taken to meet mission contingencies

c. To assist in mission housekeeping functions.

In addition to these prime tasks, the Data Processing System will be required to:

a. Perform preliminary data reduction and formatting for post-mission engineering analysis

b. Assist in IMCC and network checkout

c. Assist in IMCC and network simulation exercises.

These tasks will vary in detail from mission to mission, and will vary markedly in volume and detail from phase to phase during a given mission. Table 4.1.2-1 summarizes the major phases to be supported in the major classes of missions and denotes the increased sophistication of the more advanced missions. It also demonstrates that the Gemini rendezvous mission adds only a moderate number of new phases to the Mercury phases, but that later Apollo missions introduce markedly new phases. However, the phases employed in common during the various missions become increasingly more complex during rendezvous and lunar missions.

Table 4.1.2-1

MAJOR PHASES OF MISSIONS

PHASES	MERCURY	GEMINI RENDEZVOUS	RENDEZVOUS	APOLLO CISLUNAR, CIRCUMLUNAR	APOLLO LUNAR SATELLITE	APOLLO LUNAR LANDING
OPERATIONAL PHASES						
PRELAUNCH	X	X	X	X	X	X
LAUNCH, POWERED FLIGHT, AND INSERTION INTO LOCAL EARTH ORBIT	X	X	X	X	X	X
LOCAL EARTH ORBIT	X	X	X	X	X	X
EARTH ORBIT RETRO-SEQUENCE	X	X	X			
RE-ENTRY & DESCENT	X	X	X	X	X	X
RECOVERY	X	X	X	X	X	X
ABORT	X	X	X	X	X	X
LOCAL EARTH RENDEZVOUS		X	X			
SEPARATION WHILE IN LOCAL EARTH ORBIT		X	X			
POWERED TRANSITION FROM LOCAL EARTH ORBIT TO EARTH-MOON TRAJECTORY				X	X	X
MIDCOURSE MANEUVERS				X	X	X
SUPER-CIRCULAR RE-ENTRY				X	X	X
POWERED TRANSITION FROM EARTH-MOON TRAJECTORY TO LOCAL MOON ORBIT					X	X
LOCAL MOON ORBIT					X	X
POWERED TRANSITION FROM LOCAL MOON ORBIT TO MOON-EARTH TRAJECTORY					X	X
MOON-EARTH TRAJECTORY					X	X
LOCAL MOON RENDEZVOUS						X
SEPARATION WHILE IN LOCAL MOON ORBIT						X
MOON RETRO-SEQUENCE						X
MOON DESCENT AND LANDING						X
LAUNCH FROM MOON, POWERED FLIGHT, AND INSERTION INTO LOCAL MOON ORBIT						X
NON-OPERATIONAL PHASES						
SIMULATION	X	X	X	X	X	X
POST MISSION ANALYSIS	X	X	X	X	X	X

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4.1.3 System Design Criteria

a. The system must be capable of simultaneous full time operation for one operational mission and one simulated mission during a normal state of readiness.

b. The data processing system supporting the operational mission must be in satisfactory condition throughout mission status for any given mission.

c. There must be minimum interference between equipments and personnel supporting the real mission and simulated mission.

d. The system shall degrade proportionally in the event of equipment malfunction. No larger percentage of the system capability shall be out than the percentage of the malfunctioning equipment within the system.

e. Within the data processing system supporting the operational or simulated mission, it should be feasible to reassign functions and loads among the various equipments of each subsystem to compensate for equipment malfunctions.

f. Participation in successively more complex missions should require only evolutionary changes in the system rather than major changes. Expandability is highly desirable, and should be attainable with moderate facility or design effort. To this extent, modularity of programming, as well as equipment, is a functional necessity.

g. During either normal and emergency operation, the system must perform all functions that will provide the mission controllers with a clear understanding of the status of the mission, of trends, and of alternatives which they may effect.

h. Though extensive automation is necessary and valuable, the mission controllers must have ultimate control of GOSS so as to be in a position to make sound recommendations to the astronauts.

i. The system, including both hardware and software, must provide flexibility of operation so as to adjust to the variations in mission objectives and to adjust to the changes in plans and procedures reflecting earlier experience.

4.1.3.1 Separate Equipment for Operational and Simulated Missions

One MOCR is required to support an operational mission (both should have the capability), while the second is used for a checkout or simulated mission. These are independent activities, and must not be allowed to interfere with one another.

The simulation system will be subject to perturbations caused by (1) the setting up and checking out of the new data processing programs, (2) evaluation of new operational procedures, (3) errors made by new operating personnel being checked out, and (4) malfunctions in the several simulation subsystems involved. These perturbations must not be permitted to interfere with the performance of the operational mission.

These considerations require that physically separate data processing equipments be provided for each of the two types of missions.

4.1.3.2 Full Time Operation of Each Data Processing Subsystem

Electronic equipments of the types to be employed here will occasionally fail. It is considered to be economically feasible and operationally sensible to provide for each of the two mission activities the capability to be effective in the face of failure of one of each of the major types of equipment in the system (one computer, one coupler, etc.). Beyond this level of equipment failure, additional failures should not cause catastrophic reduction in system effectiveness. They would only partially reduce the system effectiveness, not more than the proportion of the capacity represented by the machines that have failed.

Should the data processing equipment supporting the operational mission degrade to a marginal operational level, the requirement for operation of the simulation mission would be sacrificed in the interests of reassigning equipment to the operational mission.

Any computer or data processor in a given subsystem of the data processing system must be able to perform the functions of any other computer or data processor in that subsystem.

Nonvolatile storage must be maintained at all times in such a way that it is quickly accessible to any alternate or backup data processing equipment that must undertake the processing functions in case of malfunction. This backup storage of all necessary data must be organized so that if a power line transient or processor malfunction occurs, the machine that takes over the functions will be able to automatically access all necessary status and other data that is up-to-date as of a specified time (for example, up to 2 minutes prior to the malfunction). All inputs that have occurred since this specified time will also be available for the backup processor to operate upon, to bring the system up to real time. Also, all operating programs that existed in the malfunctioning equipment will be available in nonvolatile storage for the backup processor.

A part of the executive control programs will perform the function of automatically adjusting the data processing system to meet equipment malfunctions. These programs will accomplish functions such as the following:

a. Automatic reassignment of functions that were being performed by the equipment that failed
b. Automatic reassignment of storage units, if necessary
c. Updating the backup files
d. According to preplanned rules, drop certain functions or reduce the level of performance of certain functions when necessary to adjust to appreciably reduced equipment capacity.

4.1.4 Functional Configuration

The variety of processing tasks to be performed by the Data Processing System can be broken down into three functional groups. This grouping does not imply that these separate functions should be processed necessarily in physically separate equipments, although a physical arrangement based on this concept has been considered.

Some unattractive features of a configuration based upon such a physical arrangement include:

a. Different types of computers would probably be needed for each function to provide the most efficient system at reasonable cost.

b. This would complicate the assignment of any computer to the complete functions of another in case of equipment failure since the capabilities of the different machines will be dissimilar.

c. Partial takeover of functions will be complicated by the fact that each program will have to be rewritten in the language of each type of machine considered.

d. Programming in general will be more complicated because more than one type of computer programming will have to be learned.

e. Both the hardware and software interfaces between different machines may be more complicated.

f. Training and logistics problems will be greater than when using machines of all one type.

g. If machines of all one type are used but are physically separated according to this grouping, the physical switchover of these computers may be more complicated than if all of the machines are located in one large area. This will have to be investigated.

The detailed considerations of programming task breakdowns and equipment configurations are discussed in Sections 4.2 and 4.3, respectively.

4.1.4.1 Input/Output Data Scanning and Formatting.

Extensive effort must be devoted to the automatic examination of incoming messages from the Communication Processing and Control Subsystem, determining the proper destination within the

Data Processing System, determining priority, checking for format, editing, selecting pertinent parts of the message, etc. A similar degree of effort is applied to outgoing messages.

To respond properly to the arrival and transmittal of messages and data, the system must be able to attend quickly to transmission requirements. These requirements will arrive randomly in time, occasionally peaking sharply. It will sometimes be necessary to store waiting lines of messages (queues). These requirements are sufficiently variable in quantity and sufficiently special in mechanization (real time I/0 registers, auxiliary storage for queues which must be scanned regularly) that great attention must be paid to this set of functions to assure that peak I/0 loads will not interfere with other important data processing functions, and vice versa.

4.1.4.2 Real-Time Mission Data Processing

Many mission tasks require extensive computation and must be performed at high speeds during certain phases of the mission. These are in the general area of flight trajectory and related computations. Maintaining the status of the many variables represented in the telemetered data is a high-volume, real-time task that also calls for high-speed capability with appreciable computational content. Programs devoted to the logical decisions needed to support emergencies are also required to assist in mission control.

A further reason for combining these three major tasks in one group is that they share the common requirement that, under certain conditions, there will be a requirement for performing data reduction functions on the telemetry or tracking data before the computation or status work begins.

A summary of these functions is as follows:

a. Flight trajectory computations
b. Status data processing
c. Data reduction
d. Contingency plans, logic, and actions
e. Network exercising, testing, and checkout
f. Diagnostic support
g. Weather
h. Participate in: (1) post mission analysis and (2) simulation.

4.1.4.3 <u>Display/Control Data Processing Subsystem:</u>

The displays provide organized summaries, lists, graphs, plots, etc. to the mission controllers so they can maintain current knowledge of the mission status. This output link to the mission controllers is highly interrelated with input links from those same controllers to the Data Processing System as they support the mission. The requests they make, the demands for additional information, the decisions they make, and the commands they issue are all intertwined with the data displayed.

A summary of these functions is as follows:

a. Display formatting, conversion, and generation
b. Display routing
c. Display storage
d. Instruction processing
e. Interrogation
f. Participate in: (1) post mission analysis and (2) simulation.

4.1.5 IMCC Basic Timing

The success of the many missions to be controlled by the Integrated Mission Control Center depends upon time synchronization among stations of the world-wide GOSS network. Within the IMCC itself, much of the value of processed information is dependent upon accurate generation, referencing, and communication of timing data. For these reasons a basic timing system is required.

Figure 4.1.5-1 shows a block diagram of a basic timing system for the IMCC. None of the equipment is shown duplexed, but further study may show that duplication of some or all blocks is required to ensure adequate reliability. There are two sources of basic timing in the system. One source is an ultrastable oscillator which will drive the entire timing system. In the IMCC construction time period, one megacycle crystal-controlled oscillators having a frequency stability of better than one part in 10^9 per day will be available. The second timing source will be NBS radio station WWV.

In operation, the oscillator is counted down by frequency dividers into a group of lower pulse rates as required by other IMCC equipment. One of the important low rates produced is one pulse per second. Pulses occurring at the 1 pps rate are sent through a delay network which delays them a time equal to the sum of the WWV signal transit time to Houston plus the WWV receiver delay. (This delay will be approximately 7.5 milliseconds.) These delayed pulses are presented on an oscilloscope simultaneously with once per second tone bursts derived from the transmitted WWV signal. (The WWV signals are, of course, automatically delayed by the transit time of the signal and by delays in the WWV receiver.) An observer views the composite oscilloscope display and manually adjusts the frequency divider to achieve pulse coincidence.

A second important low rate produced is sixty cycles per second. Pulses occurring at the 60 pps rate may be sent through a power amplifier and converted into a 60-cycle 110 volt power source for IMCC wall clocks. This probably will not be necessary, since most commercial power is

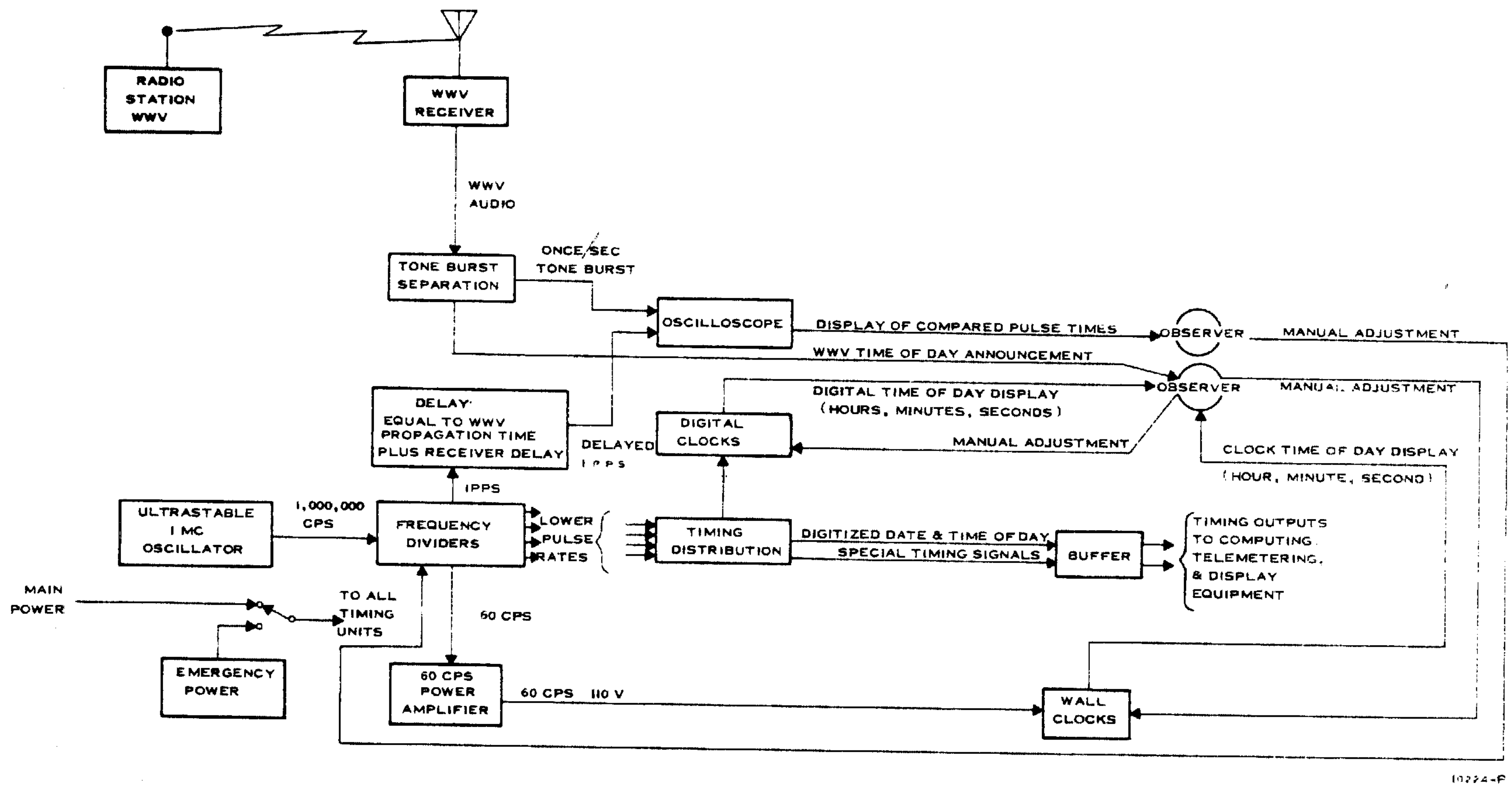


Figure 4.1.5-1 Block Diagram of IMCC Basic Timing

sufficiently accurate and stable for the job. An observer monitors these clocks and manually sets them to coincide with "time of day" announcements received from WWV. A similar closed loop is shown for digital clocks driven by other low pulse rates.

The remaining low pulse rate outputs of the frequency dividers (now synchronized with Greenwich Mean Time as a result of comparison with WWV) are used to generate time code words and special timing signals as required by other IMCC systems. Buffering is provided to make these words and signals compatible with the computing, telemetering, and display subsystems. It is not yet decided whether the computers of the IMCC will take in timing data by reading it in under program request, by being interrupted on a regular basis by the timing system, or by generating their own timing based on sharing timing system basic pulse rates. A combination of the above techniques may provide the best solution. Since these factors, together with the choice of display equipment and amount of telemetering equipment, cannot now be specified, the design of the timing distribution and buffering equipment must await those specifications.

4.2 PROGRAM DEVELOPMENT

4.2.1 Programming Tasks

The major and secondary data processing tasks previously outlined may alternatively be organized as follows in terms of the computer programs required to accomplish these tasks.

a. Simulation Programs

b. Mission Programs, Functional

1. Mission Direction Programs
   (a) Direction of Operations Program
      (1) Operations Director
      (2) Flight Director
      (3) Assistant Flight Director
   (b) Flight Dynamics Programs
      (1) Flight Dynamics Officer
      (2) Assistant FDO for Titan/Gemini
      (3) Assistant FDO for Atlas/Agena
   (c) Vehicle Systems Status Programs
      (1) Vehicle System Officer
      (2) Vehicle Systems Status Advisor: Agena
      (3) Vehicle Systems Status Advisor: Gemini
      (4) Vehicle Communicator
      (5) Flight Test Assistant
      (6) Biomedical and Environment Monitor
   (d) GOSS Network Control Program
      (1) Network Commander
      (2) Remote Site Coordinator
      (3) Operations and Procedures Officer
   (e) Recovery Forces Program
      (1) Recovery Commander

   The Mission Programs outlined above are constituted from units of the following sub-programs, which are utilized to support all the phases of Gemini and Apollo.

2. Functional Sub-Programs
   - (a) Flight Trajectory Computations
     - (1) Powered Flight Trajectory Program
     - (2) Satellite Orbit Ephemeris Program
     - (3) Acquisition Program
     - (4) Satellite Orbit Differential Correction Program
     - (5) Re-entry and Impact Prediction Program
   - (b) Vehicle Navigation Checks
   - (c) Provide Data or Program for On-Board Computer
   - (d) Weather Processing Program
   - (e) Display and Control Formatting and Generation
   - (f) Common Status Data Processing Programs
   - (g) Input/Output Data Handling
     - (1) Control Program
     - (2) Data Reduction
     - (3) Confidence Levels
   - (h) Contingency Plans, Logic, and Actions

c. <u>Mission Programs, Control</u>

1. Executive Program
   - (a) Interrupt Program
   - (b) Network Exercising, Testing, and Checkout
   - (c) Input/Output Data Handling

d. <u>Postflight Data Reduction</u>

e. <u>Network Countdown Program</u>

4.2.2 Simulation Programs

Simulation is considered one of the major functions to be performed by the IMCC. The functions of the Simulation and Checkout System are reported in Section 6.

4.2.3 Mission Programs, Functional

For a real-time control system of the scope embodied in the Gemini/Apollo missions, the job of creating, checking out, and maintaining the required computer programs is very large. It is, therefore, proposed that the programs be divided and subdivided until the programming tasks can be broken down into manageable units. It should be made clear that each of these programs will have different segments that are used during different phases of the mission, and each of these program segments may consist of a subset of program segments pertaining to different missions (i.e., Gemini Qualification Flight, One-day Flight, Seven-day Flight, etc.). For convenience, each of these segments may be referred to by a symbol such as B^2_3, C^7_3, A^4_1.... defined as follows:

Letters refer to the basic program name:

A - Mission Control (Operation Directions portion)

B - Mission Control (Flight Dynamics portion)

C - Mission Control (Vehicle Systems portion)

Superscript denotes the phase of the mission:

1 - Pre-launch

2 - Launch, powered flight, insertion into orbit

3 - Local earth orbit

Subscripts refer to a particular program within that phase:

1 - Gemini qualification flight

2 - Gemini one-day flight

3 - Gemini seven-day flight

Therefore, B^2_3 will refer to a program segment in the flight dynamics program for the second phase of a seven-day flight.

With programs subdivided in this manner, there will exist an array of available program segments. From such a supply of program segments, the executive program will prepare a mission program tape, which will contain all the programs necessary for the execution of that mission. The executive program initiates the following steps:

a. Read the proposed mission plan

b. Select the programs necessary for the execution of the mission plan

c. Prepare a written copy of the listed programs and associated directions

d. Initiate the mission program when so directed.

An important product resulting from organization of the program segments in this manner will be that a program segment, such as D^3_2, can be written as an independent routine, which permits checkout without another set being used. If desired, a set of programs B^1_1, B^2_5, B^3_2, ... B^7_6, which are concerned only with the functions of the flight dynamics group, can be checked out. It may be found that these segments will not change from phase to phase, but this is only a minor saving. More importantly, this scheme provides for alteration of any program segment without destroying the entire program.

4.2.3.1 Mission Direction Programs

The common veins throughout a mission are the mission direction programs. The program set is divided into five programs to correspond to the major areas of flight operations in the MOCR. The functional operating positions served by these programs are listed below.

a. Direction of Operations Programs
   1. Operations Director
   2. Flight Director
   3. Assistant Flight Director

b. Flight Dynamics Programs
   1. Flight Dynamics Officer
   2. Assistant FDO for Titan/Gemini
   3. Assistant FDO for Atlas/Agena

c. Vehicle Systems Status Programs
   1. Vehicle System Officer
   2. Vehicle System Status Advisor: Agena
   3. Vehicle System Status Advisor: Gemini
   4. Vehicle Communicator
   5. Flight Test Assistant
   6. Biomedical and Environment Monitor

d. GOSS Network Control Programs
   1. Network Commander
   2. Remote Site Coordinator
   3. Operations and Procedures Officer

e. Recovery Forces Programs
   1. Recovery Commander

During certain phases, these mission control programs do very little or may be extremely busy. Some part of these five programs is in memory throughout all phases of the missions.

The mission control programs furnish the means for the various control personnel to obtain information concerning the current mission phase. They also provide capability for analyzing the progress of the mission and predicting its future course. If need be, the mission direction programs can provide the necessary abort instructions for this phase and, if so directed, can enter into the abort sequence.

a. Direction of Operations Programs. The programs for operations direction will in many cases utilize the outputs of the programs supplied for other functions. These programs will be concerned with the outputs of the system status data processing which pertain to the IMCC. This will include the status of each of the major subsystems, status of major equipment in each subsystem, and expected time to full operation of each subsystem and overall system. The status of the launch force will be processed by these programs. This will provide the MOCR with the countdown time, expected hold down time, equipment status, astronaut status, availability of narrative, weather, and launch initiation. Programs will be provided to permit a high degree of man-machine communication ability for the performance of operations.

b. Flight Dynamics Programs. The Flight Dynamics programs will provide system status investigation of those items pertaining to flight dynamics. The flight trajectory status includes trajectory in or out of acceptable bounds, abort status, and alternate mission status. The set of flight trajectory computation programs will be available to the operations direction programs. In addition, there will be other programs to assist the Flight Dynamics Officer in the carrying out of his duties.

c. Vehicle Systems Status Programs. This set of programs will support the activities of the Vehicles Systems Officers and the Vehicle Communicator, and those who work directly with him. The program will provide status information on all vehicle equipment (including environmental) and biomedical sensors. Program routines will also be written to display information needed by the mission controllers to anticipate contingencies, and to plan and initiate action when emergencies arise.

1. Capsule System Status

(a) Guidance programs will operate on variables such as attitudes, stick position, rates, on-board command signals, programmer, horizon scanner, accelerations, gimbal positions, and guidance data.

(b) Capsule environment programs will provide variables such as environment temperature, temperature probes, static pressure, and impact sensor data.

(c) Capsule condition programs will provide results on variables such as voltage, currents, tank quantity, tank pressure and temperature, oxygen tank pressure, main tank pressure, and main tank quantity.

(d) Capsule events programs will provide functional and mechanical status.

(e) There will be programs to provide for other status conditions such as on-board time and voice.

2. Personnel Status

(a) Programs will provide electrocardiogram, body temperature, and respiration status.

(b) Physiological environment programs will provide information on items such as the status of oxygen partial pressure and quantity, total pressure, carbon dioxide partial pressure, cabin temperature, radiation counter, dosimeter, and humidity.

Many of the status displays will be generated automatically but there will be provision for processing special requests of the appropriate mission controllers in the MOCR.

d. GOSS Network Control Programs. The programs necessary to assist in the carrying out of the functions of the GOSS Network Commander, the Remote Site Coordinator, and the Operations and Procedures Officer will include control of the status displays of the ground network. For example, these programs will give the tracking ability, down telemetry, up data, voice receiving, acquisition, expected time to full operation, expected time to failure, data processor status, etc.

Also control of the status displays which are concerned with communication will be provided. These programs will enable the mission control personnel to communicate with the data processor and request special displays concerning the GOSS network.

e. Recovery Forces Programs. The programs for the Recovery Commander (or his representative in the MOCR) will have the ability to control the status displays concerned with the following:

1. Recovery weather for each site. The programs will display the status of ceiling, visibility, surface winds, and, if appropriate, the sea state.

2. Recovery force at each site. These programs will display the status of the force, number of vehicles, expected time that force will be operational, the range capability of the force, etc.

3. Non-site recoverability. The programs will give available data for recoverability at all parts of the world other

than the standard recovery areas. These programs will be able to search the files and display the information using either printers or display equipment at the request of mission operations personnel.

4. Status of recovery process. The programs will provide control for displaying progress of the recovery operation.

4.2.3.2 Functional Programs

The class of programs available to the mission controllers at all times are the functional programs. These are the programs which compute trajectory and orbit calculation, vehicle navigation checks, weather calculations and other programs which may be required at any time during the mission but are not associated with a specific task.

a. Flight Trajectory Computations. Flight trajectory computations will require a collection of macro-program units which, in various specialized forms, are capable of carrying out the functions associated with a series of space missions. Such a group is described here in general terms. It fulfills the programming requirements associated with that class of Earth satellite missions up to and including the Gemini rendezvous mission.

The general function and the most practical approach for each program are presented. In addition to the five macro-program units described below, the flight trajectory program will require a basic program library of mathematical subroutines. This set of routines should include: trigonometric functions and arc-functions, square root, exponential, logarithmic, interpolation, matrix inversion (n x n), integration (Runge-Kutta with fixed or variable step size), and various other functions.

1. Powered flight trajectory program. The powered flight trajectory is typically simulated by means of a six-degree of freedom program which computes a position and velocity ephemeris. This computation is based on the equations of motion of a three degree of freedom vehicle thrusting in a three dimensional inertial framework, taking into account the aerodynamic and oblateness perturbative effects. The calculation of the forces acting on the vehicle will probably employ Cowell's and/or Encke's methods, which consists of a direct evaluation of the above accelerations, an integration by some numerical method, and the use of the new position and velocity data obtained from the integration to continue the process. The program must have the capability to stage the flight in terms of powered and coast phases, and also must simulate the jettisoning of portions of the mass configuration.

A large amount of the data describing the conditions for this computational simulation will be in the form of tables requiring high speed storage allocation. Examples of such tables include: atmospheric density, attitude control, aerodynamic lift and drag coefficients, moments of inertia, chamber pressure, and wind data. This by no means exhausts the list of possible entries, but serves as a guide in storage planning.

2. Satellite orbit ephemeris program. This program computes the position and velocity of an earth satellite and its orbital lifetime, given elements of its orbit at some epoch. It must be capable of accepting epoch values of these elements in any of several forms. The forms may be, for instance, components of position and velocity, classical elements, or a specialized set of orbit parameters designed for a particular type of orbit. An example of the latter would be a specialized set of orbit elements designed to circumvent the singularities incurred in the use of classical elements to compute the ephemeris of a near-circular orbit.

   The perturbative effects of the non-spherical earth and atmospheric drag must be incorporated in the program, keeping in mind that the vehicle is operating in the transitional drag regime. The above perturbative effects and lesser perturbations, like those caused by the Sun, the Moon, and radiation pressure should be included as program modules. This would allow these effects to be included if deemed necessary, or otherwise locked out of the computation. Lock out of the lesser perturbations would be expected for the normal low altitude, short duration, manned satellite mission. The numerical integration utilized in this program should take advantage of the variation-of-parameters technique. This approach develops the equations of motion in terms of parameters which remain invariant in the absence of perturbations to the two-body motion, the dominant two-body term being suppressed. A process of this nature is quite effective in the integration of earth satellite orbits where the two-body approximation is valid over a portion of the trajectory. This permits much larger integration steps than would be allowed by the Cowell integration of the total acceleration on the vehicle. Closed form equations of motion could be used for near earth orbits.

3. Acquisition program. The purpose of the acquisition program is to compute look angle data for the remote tracking sites. The process is one of interpolating into the available satellite ephemeris for its rising time on the sensor's horizon. This ephemeris must contain points at intervals such that any pass over any stations would not be missed. The general steps in this program are:

   (a) A coordinate transformation to ascertain whether a given ephemeris point is above the horizon of the sensor

   (b) Upon establishment of the time above a station's horizon, an interpolation in the ephemeris for the rising time relative to that station

(c) A representation of the rising time and subsequent times (e.g. one minute intervals) in the Satellite Orbit Ephemeris Program to obtain position and velocity data, and

(d) A coordinate transformation of the position and velocity data to obtain the required acquisition information consisting of time, slant range, and angles.

4. Satellite orbit differential correction program. The elements of an earth satellite orbit can be corrected by means of accumulated observational data from remote tracking sites. Computationally, this process is one of forming residuals between the actual observations and the observations computed from the current set of orbital elements, and then adjusting the elements to best fit these residuals. Analytical cause-and-effect linear relationships are utilized in the fitting process since the differential characteristics of a slightly perturbed satellite orbit are, to a first order, identical to those of the true orbit.

   To correct the six orbit elements, six observational quantities are required. In general, a larger volume of data will be available, calling for statistical methods in the fitting process. A least squares matrix inversion technique is generally employed in this type of over-determination, and is recommended in this particular application.

5. Reentry and impact prediction program. A program must be available for the computation of the trajectory of a vehicle during the reentry phase of any space mission: orbital, sub-orbital, or super-orbital. This program assumes the ephemeris integration when the drag perturbation accounts for an appreciable fraction of the total vehicle acceleration (approximately 0.1 g) and continues the computation to provide an impact point.

   A Cowell integration of the total acceleration will yield all of the trajectory information that is implied in the data and in the knowledge of density, lift and drag coefficients, structural ablations, winds and many other effects for which only limited data is available. This process implies the storage requirements imposed by the tabular data for the above information.

b. Vehicle Navigation Checks. The programs required here are for backup of the on-board navigational equipment and consist primarily of those described under maneuver computations in the preceding paragraphs. In the Gemini rendezvous missions, these checks are a part of the many maneuvers that are partially controlled from the ground. The same type of programs should be performed during the phases when complete control is primarily in the Gemini vehicle (rendezvous proper, retrosequence, reentry, and descent).

The programs here must also be consistent with the on-board computer programs to the extent that they can accept the same types of input data and produce equivalent outputs or control signals. While this may be no serious restriction, it must be kept in mind so that puzzling disagreements between ground computer and space-borne computers do not occur in those cases where it is considered desirable to compare the results of the two computers before initiating a maneuver.

c. Provide Data or Program for On-Board Computer. Any section of the program in the on-board computer that can be loaded with on-board equipment should be stored in the IMCC Data Processing System. It should be stored in a form suitable for direct transmission to the spacecraft, which will probably require storage in format and code different from that used by the ground data processors. Therefore, there is probably a need for a program for loading or transforming the program as it is loaded into the IMCC data processors. Special attention should be given to any restrictions imposed by the transmission links, since any up-transmission of this type will go via remote sites.

The possibility of storing this program at remote site data processors so as to be available for transmission upon an appropriate instruction from IMCC will be examined. While this would relieve the IMCC processors of some storage and programming requirements, provision must be made for this capacity in the IMCC until and if it is decided that the remote sites definitely should perform this function.

Data for the on-board computer may be provided in modest amounts prior to launch. For reentry computations, data, such as the following, will probably be loaded:

1. Target latitude
2. Target longitude
3. Three precomputed functions of 25 points each (functions of a quantity proportional to density altitude)
4. Nominal reentry velocity
5. Angle of reentry velocity
6. A stored function of a computed quantity
7. Several constants.

Programs required for these are covered in the flight trajectory computations above. Moderate additional subroutines will provide the quantities of the types listed above.

During the mission, data and instructions computed on the ground and sent to the spacecraft include such things as orbital correction data, thrust vector orientation, velocity increment, etc. for modifications of the orbit. Also, data inputs such as the following may be transmitted to the spacecraft before reentry:

1. Predicted tangential velocity at nominal start of guidance
2. Predicted flight path angle at nominal start of guidance
3. Predicted radial distance from earth geocenter to spacecraft at nominal start of guidance
4. Orbit angle from equator to retrofire point
5. Orbit angle from equator to start of nominal guidance point
6. Angular difference between X-axis and Greenwich meridian at initiation of reentry guidance
7. Direction cosine constants
8. Sensitivity coefficient constants
9. Time to retrofire
10. Time to initiation of guidance and control to programmers.

d. Weather. A program must be provided for handling the weather status information inserted into the system so that it can be presented in proper form to the Recovery Commander when requested by the recovery forces program, or the direction of operations program. The weather status filed in the data processing system includes information on such things as winds and cover at the launch area, recovery areas, remote sites, and world-wide. Solar weather information may be stored, suitable for flare prediction and its affects on communication, and suitable for high altitude air density computations.

A real-time computational task must be performed during those parts of a mission when reentry is imminent (planned or emergency). High altitude air density estimates are needed for skip maneuver type returns to earth and reentry from earth orbits. This computation will assist in predicting accurate impact area.

e. Display/Control Formatting and Generation. The programs dealing with display/control formatting and generation will generally operate independently except for control functions, which will be handled by the executive program. If a request for an existing display or one in the files is made by a mission controller, the executive program recognizes this and relays it to the display program. If the request requires a display which necessitates extensive computation, the executive program will first secure the necessary results of the computations and send these with the request to the display routine for action.

1. Display record maintenance. A major part of the display data processing work will consist of maintaining a basic record, in electronic storage, for many of the displays in the IMCC. The classes of information to be displayed are identified in Section 5. In each of the basic records in this extensive set of records, the following is likely to be stored:

   (a) Anticipated variation of the variable(s) in question throughout the mission, whenever such values are needed for display or contingency computations. Normally, these would be calculated prior to the start of the mission.

   (b) History of variable(s) during mission

   (c) Current status of variable(s), with time tag to make the currency of the data clear

   (d) Projected values of the variable(s), based on experience during the mission to present time, if appropriate.

2. Generation of display formats. For each of the major kinds of display equipment driven by the data processing equipment, there exists an appreciable quantity of work in translating data from the basic record storage to the sequence and form suitable for transfer to the displays. This may include such tasks as:

   (a) Developing the proper sequence of data prior to transfer to a display device

   (b) Developing information to tell the display equipment the coordinates of the symbols or lines to be displayed. This may require transformation of coordinate systems used in the mission proper to coordinates for the display device itself.

   (c) Developing control signals required by the display equipment (beginning of message, end, beams on and off, etc.)

   (d) Scaling to fit data into predetermined scales for display

   (e) Transformation of alphanumeric information into standard symbols, lengths of lines, etc., for display

   (f) Conversion of alphanumeric information for display, such as binary to decimal symbols, etc.

   Section 5.2 presents a description of the kinds of data which are to be displayed. For the purposes of determining computer program requirements for these tasks, it is necessary to consider in greater detail the sources of this data, the rates and formats of inputs to the display/control computers, the extent to which this data must be prepared for display, and the output rates and formats for display.

(a) Pictorial displays. The first class of displays is pictorial, and includes subsystem specifications, schematic diagrams, parts, lists, illustrations, mission rules and other information which could be displayed when required for a quick look at design, maintenance, or operational procedure information. Because of the extreme data storage requirements and execution times needed for driving this type of a display, it is recommended that the off-line data files, as described in section 5.4, be used as a data source rather than the data processors.

(b) Dynamic displays. The second type of display is dynamic and consists of computer-generated displays such as trajectory plots. It is advisable to provide the capability of displaying several different kinds of data and curves to each monitor console. For the majority of the displays, background and scale information will be supplied by scanning of previously-drawn slides which are provided in the display scan generators. For special cases, a computer program may develop the scale information. An example of the information shown on dynamic displays is "vehicle height above the earth's surface versus longitude." Included in this type of display might be several numeric values; for example, current vehicle height and longitude for which this computed height is valid. Another display might contain impact latitude or longitude for immediate abort versus system time and appropriate current values.

(c) Trend/graphic and numeric displays. Trend/graphic and numeric displays (including time) will require programs which are similar to those for dynamic displays. It will be possible, therefore, to use common subroutines for both these types of displays in many instances.

(d) Event displays. Events are normally displayed by igniting one out of two or three lights on a console to signify whether an event has occurred early, on time, or late with an associated numeric display to specify time discrepancy. Status information is provided similarly to indicate go, no-go, on-off and other conditions met or not met. For these displays, single binary bits are used to signify a true or false condition for each possible light on a display panel. Logic is usually provided at the display panel to interrogate this data which ignites a light for each corresponding binary one and extinguishes a light when its associated binary bit is a zero. For purposes of computer storage and data transfer, these bits are packed together into computer words.

3. Display routing. The data processing equipment must maintain information stating which display is to receive which information. Standard operating procedures will define this. The equipment will assign the proper address(es) for transmission to the proper display(s).

4. Display control program. A control program providing for the automatic generation of display information will be written. This program is concerned with the technical aspects of the display, i.e., the regeneration cycle, and with reformatting of the display information due to a change in the data. The mission direction programs will control the responses for creating a new display and, once the parameters for this display have been established, control for formatting and generation will pass to this program.

5. Interrogation. The mission controllers must be provided means for interrogating any part of the ground or space-borne system for information or for diagnostic purposes. Therefore, programs are provided for this subsystem to assist in such interrogation. On signal from the mission controllers, suitable interrogation commands will be automatically formulated, addressed, and transmitted, Monitoring for the return information will be established, and the requested information will be displayed or otherwise presented.

f. Common Status Data Processing Programs. This work consists primarily of maintaining a large number of records of the status of the many variables listed in the tasks above. These unit records may initially contain planned variation of the variable throughout a mission, acceptable ranges, or other quantities needed for comparison through the mission. During the mission, status is recorded with time tags at preestablished intervals or according to other criteria. This, then, is an extensive sorting and filing operation from the viewpoint of programming.

Preceding the actual recording in the files, each class of data must be operated upon to determine its reasonableness, whether it is in range, etc. A set of standard subroutines will be established to operate appropriately on all incoming data before installation in the unit records. Storage of the data as it arrives in historical backup records will also be wise. Criteria for selection as to which data to transmit to the Display/Control System will be associated with each class of data received. Programs that mechanize this will be provided.

The mission direction programs will be able to override any of the automatic responses through action requirements having priority

g. Input/Output Data Handling.

1. Control program. Control of data flowing into and out of the Data Processing System will be under the control of the executive program, but the details for formatting of input data for better utilization by the system will be under the control of an input/output control program. Data may need unpacking, converting to binary, or to new codes. Also, data that is to be sent out of the system or to other parts of the system may require some processing. The same input/output control program will accomplish these tasks.

2. Data reduction. For each class of data arriving at the Data Processing System, criteria to be checked for reasonableness, sampling rates, and smoothing must be programmed. These requirements will range from modest processing to relatively sophisticated concepts, especially in the area of testing for reasonableness. For flight trajectory computation, this testing must really be considered to be a part of the computation because of the extensive interrelationships.

   Scaling and calibrating may well be necessary for certain inputs for which correction factors are known. This may apply to any incoming data, although it is reasonable to assume that tracking data will be calibrated at the remote sites as part of normal operation. A catalog of meter and other calibration data must be maintained, however, for emergency use. This catalogue of correction curves may be continuously useful and applicable to tracking data, from various sites.

3. Confidence levels. Data transmitted from the remote site to IMCC may contain a confidence indicator for use by the data processing section. When the vehicle is low on the horizon or when tracking data is poor, the confidence factor may be low. When tracking conditions are ideal, the corresponding confidence factor will be high. The same criteria will apply to telemetry data. Data that has had poor reception at the remote site will have a lower confidence factor than data which has had the better reception. The input/output processing programs will have the capability for utilizing this factor in rejecting or accepting the data or the functional programs may use this factor in properly weighting these data.

h. Contingency Plans, Logic, and Actions. In the planning for contingencies, the failure of any substantial part of any subsystem must be considered, and the variation of any status more than a specified amount from bogey or plan must be considered. The consequences of each such failure or excessive variation must be established. If interrelations exist in determining the consequences, these interrelations must be thoroughly examined. These plans must be performed for each phase of a mission.

Not only must each status be tested for conformance to a specified range of values but additional anticipation should be provided to detect possible future deviations beyond acceptable tolerances by each status. This can be accomplished by mathematically varying the parameters affecting a particular status by some specified amount, either one at a time or together and then checking the condition of this status. These automatically generated, marginal tests will provide conditional trend information which may be used by the mission controllers to initiate the necessary corrective action to avoid a potential problem before its imminence would become known by observing ordinary trend charts.

4.2.4 Mission Programs, Control

4.2.4.1 The Executive Programs

a. Requirements. The executive programs will impose certain requirements upon the programs in the data processing system. These will provide the following:

1. Protection of information which is concurrently utilized by different programs
2. Assignment flexibility in that tables and files of information are determined at execution time
3. Segmentation and interruptability features to facilitate control of system environment.

Each program will maintain linkage to that part of the executive program that is required for communication. This local executive program interprets commands given to it and carries out the indicated functions itself or communicates these to the master executive program for execution. In the latter case, the master executive program executes the request and then alerts the local executive program.

Some information files may have many requests directed to them concurrently. One program may be altering data in the file while another is reading this file. This could lead to ambiguous results. As a result, no direct transfer of data to the files will be permitted. All loading of new data must be coordinated through the executive program by means of appropriate interrupts.

The loading of all program instructions and data is coordinated by the executive program. All programs will be carried in a common data sink (disc file, tape unit or drum) which can be accessed only by the executive program. Lengthy programs may be segmented, with the first segment loaded by the executive program automatically initiating the job. Other segments will be loaded but initiation will be under control of the program being executed. The length of each segment will be controlled to prevent destruction of protected data in memory.

The assignment of data stores such as tape units, drums, etc., will be made by the executive program. During the course of a mission, various components may be taken out of the system for preventive maintenance or repairs. The executive program will monitor these data stores and will make the necessary data reassignments for the program.

It may be necessary to segment programs into sections called programming phases. These segments may be used in many different phases of the total mission. Some parts of a program may not be needed for a considerable length of time. Therefore, the space needed for this segment can be better utilized by other jobs.

For integration into the system by the executive program, certain information concerning the programs must be available to the executive program for incorporation into internally stored tables. This information includes program identification, information associated with the data sink, the total extent and interruptability class of each processing phase within the program, the program names for the different information files it uses, dump parameters, and loading parameters.

The executive program must, from time to time, interrupt the execution of a program to facilitate a higher priority job. Certain characteristics of the programs make it impossible to interrupt them at the desired point of interruption. Since it is desirable to have some easily interruptable program in the execution phase whenever program pre-emption is a possibility, the executive program must take into account the interruptability characteristics of each program. To facilitate this aspect of the system operation, programs should initiate setting of preassigned bits in a program-interrupt data word. An index will be assigned each program processing phase on the basis of the longest continuous execution interval within the processing phase during which "no interrupt" condition is set. If the executive program attempts an interrupt and the program does not respond to this alert within the maximum time interval corresponding to its current interruptability index, the program is destructively dumped with no effort to preserve previous computations. If this occurs, a restart from an earlier point will be necessary to bring the system back to real-time processing. The programmers should be encouraged to make a reasonable attempt to design all programs to be interrupted as often as possible.

All processing phases except the terminal phase are terminated by an exit to the executive program with an indication specifying the next processing phase to be executed. No error stops will be permitted in any program. Indication will be given to the executive program that an error has occurred and appropriate action will be taken by the executive program. The terminal processing phase exit will alert the executive program to perform the necessary terminal tasks and to initiate the next program.

Each programmer will organize the working storage and instructions such that a minimum amount of the program need be dumped for later restart if conditions warrant such a restart. Periodic dumps will be taken during the execution of all programs.

b. Functions. The executive control programs will provide the following functions:

1. Control of the execution of all programs necessary for the successful completion of the mission
2. Collect and store the necessary data for the programs
3. Provide means for program continuation in case of malfunction of any component in the system
4. Assist in the execution of the diagnostic and system checkout during a mission
5. Provide means for modifying mission plan by eliminating phases or the initiation of abort sequences by mission control personnel.

4.2.4.2 Input/Output Control Programs

The routing, sorting, formatting, editing, and priority determination tasks will require computer programs, the characteristics of which are determined by the interfacing capability of the equipment involved, the data rates, and the transmission formats. Programs such as the following are indicated.

a. Editing. The removal of irrelevant symbols, insertion of necessary control symbols, and replacement of control symbols necessary to interface between the Communication and the Data Processing Systems

b. Validation. Checking for completeness of format, valid combinations of source address vs. type of data, and other inconsistency detection

c. Error printout. Printing out messages that do not satisfy the validation checks

d. Format preparation. Grouping of words or messages to assemble standard blocks of either incoming or outgoing data

e. Sorting. Possibly desirable if certain classes of messages can be stored and transferred at specified intervals or upon command.

f. Queue management. The committing of messages to queues and their subsequent routing according to their importance

g. Backup message storage maintenance. Directing the storage of transmitted and received messages, for use of catch-up processes instituted when some data processing device malfunctions.

Much of the workload of this subsystem is similar to that often assigned to a communication processor. Further work is required to more clearly establish the interface between these two areas.

4.2.5 Postflight Data Reduction

4.2.5.1 Data Processing System

The Data Processing System will concern itself only with the preparation of data for reduction and analysis, and will not be concerned with the actual reduction and analysis of the data itself. Information attained throughout all mission phases must be ideitnfied, categorized and stored for future use as an analytical tool and for an historical file.

This information includes IMCC generated commands and data which are transmitted external to the IMCC, information used for internal IMCC control, data used in determination of displays, and external information received by the IMCC. In addition, all raw telemetry and tracking data from the remote sites and any information not normally available to the IMCC (data used for or generated by data processing equipments at the remote sites) must also be in IMCC files.

4.2.5.2 Data Reduction Computers

The actual data reduction and analysis will take place in the Office, Laboratory and Support Wing of the IMCC by a set of computers not associated with either operational or simulation missions. These computers are not considered a part of the Data Processing System.

Sophisticated information retrieval techniques must be worked out to allow the stored volume of data to be reduced. Statistical report programs covering areas not critical to mission completion, but of significant value to mission analysis and future planning, will be written.

These computers can duplicate the remote site data processors and proper analysis of the results will prove invaluable in exploring apparent anomalies in data as received at the IMCC during the actual mission.

Information, that is preserved in this manner, may also be used in development of training courses. With the availability of this timed information, either the entire mission or specific phases may be

regenerated to supplement the extensive training exercises envisioned with simulations.

4.2.6 Network Countdown Programs

During the countdown, the multitude of planned steps and their timing and interrelationships must be thoroughly and clearly kept before the mission controllers. As holds occur, the definite consequences and the probable consequences must be made evident. An interrelated set of tasks in missions as complex as Gemini Rendezvous and succeeding missions can be usefully represented by a network such as that employed in PERT. The sequence of tasks is clearly stated, and the effect of delay in one task on the timing of the other tasks throughout the network can be made clear. The probable time to completion of countdown can be computed at all times. The tasks that are "critical", i.e., those which influence time to completion, are identified, and the amount of rescheduling flexibility in "noncritical" tasks is made clear. If the uncertainty in any task time duration can be estimated, an estimate of the resulting uncertainty in the time of completion of countdown can be computed.

The interrelations between the possible countdowns of two vehicles can also be handled by this process.

The amount of time until the next significant event(s) or decision(s) may be computed and displayed to the mission controllers at all times.

Scheduling of the various subsystems and equipments in the IMCC will be performed. The times at which facilities are to be assigned to GOSS, tested, exercised, and checked out, and when they are to be fully operational and for what time duration, would be computed and submitted to the mission controllers.

Computation of suitable launch windows would be performed, whenever requested, based on the status of the countdown and the status of interrelated vehicles in countdown or spaceborne status.

4.2.7 General Concepts

4.2.7.1 Program Preparation

A grouping of the essential elements in the generation of the data processing is as follows:

a. Mission definition

b. Hardware systems/subsystems definition

c. Program systems/subsystems definition

d. Development of programming standards

e. Flow charting and timing analyses of program subsystems

f. Coding and translation into machine language

g. Generation of validity tests and checkout of validity tests and program subsystems

h. Documentation of program material

i. Modification and integration of programs and program subsystems

j. Technical review of program systems

k. Real-time checkout and system integration.

These elements are described as follows:

a. Mission Definition. This will include a technical description of the vehicle flight path and the relevant mathematical and data processing functions. The description will also include all inputs and outputs to the Data Processing System by mission phase, with relative priorities and tolerances. The mission definition will also include the required reliability for each phase.

b. Hardware Systems/Subsystems Definition. This will be composed of a detailed description of all data processing equipments including interface requirements, input-output data formats and rates.

c. Program Systems/Subsystems Definition. This will comprise a detailed description of all required programs, sub-programs, and sub-routines, by mission phase and program development phase. The description will include the inputs, outputs, functions, failure indicators, and checkout provisions, and will thereby assign responsibility to specific subprograms and define the interprogram and hardware/program interface.

d. Development of Programming Standards. This area will encompass the standardizing of the external characteristics of the programs, the allocation of the data processing real-time facilities among the various programs, and the definition of the operating system for real-time and production use.

e. Flow Charting and Timing Analyses of Program Subsystems. This operation will provide checks for correction of initial estimates and designs. This phase also includes the specifications for all detailed coding.

f. Coding and Translation into Machine Language. This phase will include the essential elements of producing the programs and subprograms. These activities encompass the coding and code checking of the rough draft programs for compliance to the guiding specification, key punching, and verification in connection with the transcription of symbolic programs and assembly of the human oriented coding into machine oriented programs and data media.

g. Generation of Validity Tests and Checkout of Validity Tests and Program Subsystem. The problem of verifying correct operation of complex data processing is recognized as a problem of the same order of magnitude as creating the operational system. This phase will involve the preparation of data for testing the functional performance of the Data Processing System and the correction of inadequacies due to machine or programming problems and the preparation of software simulation programs. These programs would be used to incorporate the various program segments into the system and simulate only the aspects necessary to check out the mission.

h. Documentation of Program Materials. Proper and adequate documentation will result in the following advantages; (1) re-use of subroutines and common functions for future systems, (2) dissemination of new techniques throughout the data processing field, (3) review and analysis of original technical decisions, and (4) revision and modification of verified programs can be accomplished without major difficulties.

i. Modification and Integration of Programs and Program Subsystems. This will cover the effort required to redocument the debugged and verified subprograms, and the solution of problems encountered in the combination of all the operational subprograms into the operational program complex.

j. Technical Review of Program Systems. This will provide for a review of the entire program system and its ultimate performance, and a review of the final balance between hardware and software performance.

k. Real-Time Checkout and System Integration. This phase will involve an examination of pre-mission, mission, and post-mission performance. This will include pre-mission and real-time checkout; real-time operation; modification of the programming complex due to equipment, personnel, or program deficiencies; and/or modification to satisfy new and unforeseen requirements derived from post-mission performance evaluation and data reduction.

4.2.7.2 Computer Program Testing

As indicated in Section 4.2.7.1 e and g, above, the flow charting and timing analyses of program subsystems will provide checks for correction of initial estimates.

4.2.7.3 Computer System Testing

A starting point for computer system testing will include such items as (1) mission definition, (2) hardware systems/subsystems definition, and (3) program systems/subsystems definition.

Data processing diagnostic programs, for example, will serve a two-fold purpose. On the one hand, they serve as extensive "readiness" programs which determine whether or not the data processor and its associated equipment are operating at prescribed levels. On the other hand, malfunctions will be isolated if the Data Processing System is not operational. Communication diagnostic programs will serve first as a "readiness" test of the communication network and, secondly, as a routine to assist in locating the faults in the system. Such programs must have an automatic mode of operation for cycling through all data channels with operator intervention and a control mode for testing only an operator-specified segment of the system. Display diagnostic programs will also serve as "readiness" tests of the Display System and as routines to isolate the area of malfunctions. Such routines will display standard test patterns and random patterns. Operation intervention will be required to pass on the effectiveness of the displays. Simulation programs for communication will simulate the output of any device in the Communication System. These programs can be used to test other parts of the Data Processing System. They can be used, for example, to simulate the output of remote sites when checking out the software programs.

Suitable documentation will result in the following advantages:
(1) Re-use of subroutines and common functions for future systems,
(2) Dissemination of new techniques throughout the data processing field,
(3) Review and analysis of original technical discussions, and (4) Revision and modification of verified programs can be accomplished without major difficulties.

4.2.7.4 Systems and Standards

A data processing programming system of this magnitude must, of necessity, adhere to stringent rules and procedures. The executive routine will have in its system standardized subroutines, calling sequences, error returns, indicator settings, recovery techniques and interface controls. It will also embellish the idea of data bank philosophy to apply commonly used items to symbolically identifiable cells. These standards will avoid multi-program inconsistencies, reduced storage allocation and aid in the checkout of these programs.

Documentation standards will be set to insist that all programs use common formats in write-ups, similar testing techniques where applicable, common symbology for flow charting, and a common language to present a consistent, concise and explanatory document for future reference. Symbolic listings with adequate and meaningful comments must also be considered as a major contribution to any well-documented and standardized system.

4.2.8 Program Storage

Tables 4.2.8-1 and 4.2.8-2 show partial storage requirements for the programs listed. These programs are stored in high speed memory according to the function they perform. For example, all the flight trajectory programs would be in one block. This group would require 19,200 cells with an additional 200 cells for temporary storage. The display programs require 11,000 cells for program and 1,500 cells for temporary storage.

Retaining functional programs in their respective groups and including the control programs for the phase prevents overloading of computers. During the rendezvous mission phase, the greatest number of programs are in high speed storage. This requires 54,000 cells of high speed memory including program storage and temporary storage space.

Further additions to these tables will be made in future revisions to this report.

It can be said at this time that the program storage requirement does not play a significant part in selecting the optimum data processor for the IMCC. The determining factor is the time loading of the machines.

Table 4. 2. 8-1

MISSION CONTROL PROGRAMS

Mission Control

Testing and Checkout Phase Control

Pre-Launch Phase Control

Launch Phase Control

Local Earth Orbit Phase Control

Reentry and Descent Phase Control

Recovery Phase Control

Local Earth Rendezvous Phase Control

Separation While in Local Earth Orbit Phase Control

Powered Transition to Cislunar or Circumlunar Orbit Phase Control

Cislunar or Circumlunar Orbit Phase Control

Midcourse Maneuver Phase Control

Powered Transition to Local Earth Orbit Phase Control

Skip Maneuver to Local Earth Orbit Phase Control

Powered Transition from Local Earth Orbit to Earth-to-Moon Trajectory Phase Control

Earth-to-Moon Trajectory Phase Control

Powered Transition from Earth-to-Moon Trajectory to Local Moon Orbit Phase Control

Local Moon Orbit Phase Control

Powered Transition from Local Moon Orbit to Moon-to-Earth Trajectory Phase Control

Moon-to-Earth Trajectory Phase Control

Local Moon Rendezvous Phase Control

Separation While in Local Moon Orbit Phase Control

Moon Retro-Sequence Phase Control

Moon Descent and Landing Phase Control

Launch from Moon Phase Control

Powered Flight Trajectory Phase Control

Table 4.2.8-1 (Contd)

Storage Required for Above (A further breakdown is not available at this time).

PROGRAM	TEMPORARY
3,000	500

For each phase listed above, only one program at a time is in high speed storage. The others are stored on either drum, disc, or tape.

Table 4.2.8-2
FUNCTIONAL PROGRAMS STORAGE

	Storage Required	
	Program	Temporary Storage*
Simulation Programs		
Data Processing Diagnostics	8,000	1,000
Communication Diagnostics	7,000	1,000
Display Diagnostics	5,000	1,000
Simulation for Communication	10,000	2,000
Mission Programs, Functional		
Powered Flight Trajectory	10,000	200
Satellite Orbit Ephemeris	3,000	--
Acquisition	200	--
Satellite Orbit Differential Correction	1,000	--
Re-entry and Impact	2,000	--
Mathematical Subroutine	3,000	--
Weather Processing	1,000	--
Display Control	4,000	500
Display Formatting and Generation	7,000	1,000
Input Smoothing	2,000	1,000
Input Formatting	1,000	500
Input Control	2,000	2,000
Output Formatting	1,000	100
Output Control	1,000	100
Report Generation	5,000	500
Mission Programs, Control		
Checkout/Readiness	2,000	--
Data Reduction	3,000	1,000
Special Scheduling for Pre-Launch	3,000	--

*Temporary storage can be shared with other programs.

4.3 IMPLEMENTATION

4.3.1 Basic Approach

The objective of this Section is to specify the type and number of computers required in the computer complex to satisfy computing capacity and redundancy requirements. It is possible to approach this task in the classic manner by estimating the memory capacity and operations required per unit time for each of the program elements described previously adding and averaging them (with appropriate attention to peak loads) to determine the total computing load, and then selecting one or more computers with enough capacity to handle the task in real time.

For the Gemini/Apollo Data Processing System, however, this approach should not be used since the function to be performed — the support of manned space flight programs — does not follow the pattern of operational characteristics of scientific computation, business data processing, or on-line process control. It more nearly approximates, but even goes beyond, the real-time control functions of air defense network control and unmanned satellite tracking and control systems. To properly examine the data processing equipment needed for such a system, it is necessary to focus attention on the interrelations and possible conflicts that exist among a variety of tasks being carried out simultaneously and asynchronously.

Into the computer complex, a variety of information will flow: tracking data, vehicle telemetry, and status reports on the ground system and recovery forces. Out of the computer complex must go a variety of information, such as recommendations to the spacecraft crew, schedules of activities for ground network elements, acquisition data for tracking stations, and a capability to provide information to the spacecraft. Within the computer complex, the incoming data must be appropriately manipulated or transformed to produce the required output information. The key element in this transformation process is the men who have the responsibility for direct actions which control the support function. Therefore, the complement of data processing equipment cannot be specified without first analyzing the functions of the mission controllers and ground monitoring personnel for whom the computer complex is designed as a support tool.

A typical listing of the manpower needed to conduct a Gemini or Apollo mission shows approximately fifteen men involved directly in the operation seated at display/control consoles in the MOCR. These can be functionally grouped as follows (for Gemini):

a. Overall Operations Control
   1. Operations Director
   2. Flight Director
   3. Assistant Flight Director
b. Flight Dynamics
   1. Flight Dynamics Officer
   2. Assistant FDO for Titan/Gemini
   3. Assistant FDO for Atlas/Agena
c. Vehicle Systems Status
   1. Vehicle Systems Officer
   2. Vehicle Systems Status Advisor: Agena
   3. Vehicle Systems Status Advisor: Gemini
   4. Vehicle Communicator
   5. Flight Test Assistant
   6. Biomedical and Environment Monitor
d. GOSS Network Control
   1. Network Commander
   2. Remote Site Coordinator
   3. Operations and Procedures Officer
e. Recovery Forces Program
   1. Recovery Commander (not in MOCR).

Since the function of the Data Processing System is to provide the automatic data processing capability, the above men must perform their specified functions and not concern themselves with data processing. Information flow study has been carried out to determine what incoming information is needed by each of the five functional groupings of personnel, what computer program elements are used by each of these groups, what outputs are produced as a result of operations upon the incoming data, and decisions made and actions taken by the control personnel. For example, the GOSS network control group directly utilizes ground systems status information which comes in over the ground communication channels for countdown monitoring and action, for monitoring of the ground network during the mission, and for scheduling tracking station activities and communication channel usage. The GOSS network control group also needs tracking data for the generation of acquisition angles but this tracking data comes to them after it has already been operated upon by a program performing orbit calculations for the flight dynamics group. As can be seen in this brief example, consideration has been given to the various uses to which input data is put, the means by which it is manipulated, presented, and acted upon, the various types of output data, and the internal interchange of data that takes place. A listing of these mission control functions is as follows:

a. Operations control
b. Flight dynamics
c. GOSS network control
d. Vehicle systems
e. Recovery forces

In addition to these programs, which are directly identifiable with mission control functions, there are the simulation programs, the control programs, and post-flight data reduction. In this consideration of computer equipment configuration, it has been found to be logical to include the network countdown program as an integral part of the GOSS network control function. Of course, it will operate during a distinct time phase of the mission and, therefore, will be clearly separable from the remainder of the GOSS network control programs. It has also been logical to place the program segments concerned with control of remote site operations and antenna pointing information with the network control programs.

In addition to the computer programs which directly and individually support the mission controller groups within the Mission Control Center, certain general purpose program elements are required, such as display formatting, report generation, the handling of all of the functions associated with external communication lines, and an overall executive control program. As a result of approaching the design of the Data Processing System from the definition of the support functions to be performed, the following grouping emerges:

a. Operations Control
   1. Summary status reports
   2. Status of test objectives
   3. Emergency plan requests
   4. Special status report requests
   5. Contingency extrapolations.

b. Flight Dynamics
   1. Monitor current vehicle position and velocity
   2. Abort plan
   3. Reentry maneuver
   4. Rendezvous (including Agena control)
   5. Orbit determination (including ephemeris)
   6. Contingency extrapolations.

c. Vehicle System
   1. Mission monitoring (telemetry)
   2. File and sort
   3. Vehicle computer backup
   4. Contingency extrapolations.

d. GOSS Network Control
   1. Mission monitoring
   2. Network countdown
   3. Routine diagnostics
   4. Acquisition (antenna pointing) information
   5. Contingency extrapolations.

e. Recovery Control
   1. Recovery force status
   2. Weather monitoring
   3. Contingency extrapolations.

f. Display
   1. Display format and refresh
   2. Special display generation
   3. Contingency extrapolations.

g. Input/Output
   1. Intercomputer
   2. Contingency extrapolations.

It should be noted in the above tabulation of computer functions that, in each case, provision has been made for programs and computing capacity to handle contingency extrapolations. This has been done to ensure that the initial computer complex equipment will have adequate capacity to contain programs for real-time logic and computation to assist in selection of alternative mission plans and to predict future positions and velocity of the spacecraft for a range of possible conditions around the presently-known velocity factor.

All of the major computational blocks, given above, have been estimated in detail with the objective of first determining the largest single block of integral computing capacity needed for each function. With this base point established, consideration has been given to the grouping of other computational blocks whose operating characteristics are such that they could be programmed and run within a single computing element without conflict. As a result, it has been found that the largest block of computation is that required to support the flight dynamics group. From this base point, three other logical groupings of computational tasks have been determined as shown below. These were arranged to provide approximately equal-sized loads. The four basic modular computational elements selected are given below:

a. Flight dynamics

b. Network control
Vehicle systems

c. Display
Operations direction
Recovery control

d. Input/Output [illegible]

With this functional grouping established for the computational task to be accomplished, consideration can now be given to the data processing equipment required to accomplish this task. Two basic approaches to equipment design have been considered. The first consists of selecting four identical computers of a size sufficient to do the largest single computational task, flight dynamics. The second approach consists of the selection of a single machine large enough to do the entire computing task. A complete description of the computer loading figures used in this selection process and of the various advantages and disadvantages inherent in the two approaches is given in the paragraphs which follow.

4.3.2 Peripheral Equipment Considerations

4.3.2.1 Communication System Interface

It is necessary for the IMCC Data Processing System to be able to communicate with the external world. This external world consists of a number of high-speed data lines and low-speed data lines to remote sites and to Goddard Space Flight Center, displays in the Mission Operation Control Rooms and support areas, and control originating in the MOCR or support areas. In addition, it is possible that the Data Processing System may be called upon to process text messages between persons in the IMCC and other locations.

It is possible to combine the functions of communication data processing and routing in the same Data Processing System that performs all the operational computations for the GOSS network. On the other hand, it is not necessary to so combine functions, and it may not be desirable to do so. For this reason, several possible configurations of the Communication and Data Processing System have been considered. The block diagram for such a configuration is shown in Figure 4.3.2.1-1.

Lines from the remote sites and GSFC enter the IMCC through modems, and may be switched either directly to a message center or to a buffer and thence to a communication computer. The communication computer, in turn, may be connected either to the message center or to the operational computers, or both. The operational computers drive the displays in the IMCC and accept control messages.

Another possibility that must be considered is that of separating the communication computer from the remaining computers in the Data Processing System. The computer-loading studies have indicated that this may be done efficiently without requiring an increase in the overall data processing system. The advantage of divorcing the communication computer from the remainder of the Data Processing System is that, in both the mission and non-mission modes, one computer may be used effectively to control operation of lines to the external world and to route messages to various places within the IMCC.

4.3.2.2 Display Selection and Driving

This section discusses the considerations that will determine the structure of the subsystem between the display/control data processors and the display equipment proper.

a. Types and Numbers of Displays. Major determinants of the characteristics of the selection and driving equipments are the quantity and types of displays. Table 4.3.2.2-1 presents basic display types, display media and presentation techniques. The three basic types of presentation technique may be displayed on electronic or electric devices, or on hard copy. The latter takes three forms as indicated in Table 4.3.2.2-1. Table 4.3.2.2-2 indicates the media in which the three types of presentation will probably be displayed.

b. Major Output Channels. These considerations suggest an initial identification of a suitable set of output channels from the data processors toward the displays, described in Table 4.3.2.2-3. Each of these types of terminal display equipment calls for different types of data format, signal characteristics, and driving power. It appears reasonable to consider a channel designed for each.

1. For Channels 1 and 2, preliminary estimates suggest that the updating traffic is so low that it will be feasible to serve the large number of terminal devices through an electronic selection matrix that can serve only one indicator at a time. Traffic studies will be conducted to test this concept, possibly leading to a requirement for additional servicing channels.

2. For Channel 3, the present concept for display of dynamic information is a closed-circuit TV system. An estimated 47 TV monitors are served by 28 scan-converter units for coupling to the data processor outputs and 10 miscellaneous video inputs. A scan converter is capable of storing an image for a period of 1—5 minutes before it must be regenerated (or replaced).

   A relatively straightforward method of coupling from a data processor to the 28 scan converter units would be to provide a multiplexer whose pole is connected to the data processor output channel and which steps regularly through 28 output lines connected to the scan converters.

   Each scan converter would be designed to signal when it needs a regeneration, or else the regeneration can be made to proceed on a regular cyclic basis. When new information arrives in the data processor, (1) it can write the new information on the scan converter without waiting for a regeneration cycle (this assumes no erasing of old

Table 4.3.2.2-1
TYPES OF DISPLAYS

Type	Basic Presentation	Types of Display Media
Events	Three Level	Electronic and Electronic
Time	Eight Digits (max.)	Hard Copy
Dynamic	Graphic-Curves	Plotboards
Numeric	Three to Eight Digits	Strip Plotters
Trend	Graphic-Curves	Alphanumeric Printers
Status	Three Level	

Quantities of Displays (Preliminary Estimate)

Regrouping by Type of Basic Presentation	Approximate Quantity of Type
Three Level	400
Eight Digit	50
Graphic-Curves	100

Table 4.3.2.2-2

RELATIONS BETWEEN TYPE OF PRESENTATION AND MEDIUM

	Electric Electronic	Hard Copy		
		Plotboards	Strip Plotters	Alphanumeric Printers
Three Level	X			X
Eight Digits (max.)	X			X
Graphic-Curves	X	X	X	

Table 4.3.2.2-3

MAJOR OUTPUT CHANNELS

Channel	Purpose
1	Drive Three-Level Indicators
2	Drive up to Eight-Digit Numeric Indicators
3	Drive Electronic Dynamic Graph, Curve, etc. Displays
4	Plotboards
5	Strip Plotters
6	Alphanumeric Printers

information is required), (2) it can hold the new data points until the next regeneration cycle, or (3) if the priority of the new data calls for immediate up-dating, the pertinent scan converter can be erased and a new plot made.

The time required to paint out a display on the input to the scan converter depends on (1) the number of inches of line or the number of line-segments required to paint out the display, (2) the beam writing speed suitable for the particular scan converter, (3) the yoke settling time, (4) the characteristics of the driving amplifiers, etc. Preliminary estimates range from 0.1 sec to 1 sec average for painting out one display. Using the simple multiplexer, the performance results are summarized in Table 4.3.2.2-4. Note that if the average painting time is as low as 0.1 second, then the updating rate and the time for response to a computer display request may be acceptable. Updating would be occurring each 2.8 seconds on the average, where appropriate to keep up with fast moving situations. Note also that even if the average painting time is as high as 1 second, the stepping multiplexer can make the rounds to 28 scan converters well within the shortest regeneration time (1 minute).

Table 4.3. 2.2-4

PERFORMANCE OF SIMPLE MULTIPLEXER

Time to Paint Display on Input to Scan Converter (Average)	Updating Frequency for Each Scan Converter (Average)	Computer Display Request Response Time (Average)/(Max.)
0.1 sec	21.4 per min	1.9 sec/2.8 sec
0.5 sec	4.3 per min	7 sec/14 sec
1.0 sec	2.1 per min	14 sec/28 sec

If further study proves the 0.1-second average to be optimistically short, or if the updating frequency or response time is inadequate, an addressing feature may be incorporated in the amplifier. A register would be provided that can be set by the data processor for transmitting high-priority information to an appropriate display in minimum time. A counter would be provided to conduct a stepping operation when a computer display request occurs, requiring that the multiplexer seek an unused scan converter. The addressing register may also prove useful in responding to regeneration signals from the various scan converters, if these regeneration signals are handled as interrupts at the data processor.

3. Channel 4 may requre a number of nearly full-time on-line channels, but the rate at which points must be fed to these plotboards may make it feasible to time share them through a single output channel from the data processor.

4. Channel 5 may require more than one on-line continuous channel. Again, the possibility of supplying data to the several strip plotters via a multiplexer or high-speed selection system to cause them to share a common output channel from the data processor must be examined. Also, where appropriate, certain strip plotters may be driven from information patched directly to the plotter rather than transmitting it via the data processors.

5. Channel 6 will probably require a number of full-time standard output channels for supplying data to on-line printers.

c. Symbol Generation. In Channels 2, 3 and 6, where alphabetic, numeric and other symbols are included in the presentation, equipment must be provided to transform the electrical codes used by the data processor into the corresponding symbols that are meaningful to humans.

1. In Channel 2, the form of signal required to set the digital or alphabetic indicators will usually be different than the code used by the data processor. If possible, the conversion equipment to produce the necessary indicator signals should be placed in the vicinity of the data processor and ahead of the selection matrix. Solid-state latches are recommended at the indicators, both for reliability and to reduce the noise level in the vicinity of the viewers.

2. In Channel 3, extensive manipulation is required to generate and position the symbols. Two major alternatives are open at the outset:

   (a) Generate within the data processing machine the digital information suitable for painting and transmitting each symbol (number, letter, or other symbol)

   (b) Provide on-line symbol generation equipment that can accept the data processor code for a given symbol and generate the information required to paint out the implied symbol.

   The second alternative, on-line symbol generation, will be considered initially since only a few generators are required and it is believed that the equipment costs will be less than the creation and maintenance of the computer program routines required for computer-generated symbols.

If a few symbols,which cannot be readily generated by the digital-to-analog equipment, are required, computer subroutines can be written for these special symbols. This capability makes it possible to change symbol structure if changing missions so require.

It is recommended that the symbol-painting information be transmitted to the display digital-to-TV conversion devices in digital form, for digital-to-analog conversion there. This is suggested to avoid electronic noise problems on the transmission lines and grounding problems and since it is more convenient to confine the dc-coupled circuits (necessary in the amplification of the analog deflection signals) to the vicinity of the scan conversion tubes.

3. In Channel 6 the conversion system is built into the output channel and the printer.

d. Driving Other Terminal Devices. For Channel 1, to the three-level indicators, digital or pulse transmission is envisioned at present, with solid-state latches or switches at the indicators (unless such storage, switches, or equivalent are integral parts of the indicators). Conversion from data processor code to signal required by the indicators would best be performed ahead of the selection matrix, perhaps by the data processor program.

For Channels 4 and 5, plotters driven by the digital data processors, digital transmission to D/A converters at the terminal device itself is proposed at present.

e. Backup Equipment. Scanners, stepping switches, and multiplexers will be fitted with surplus channels and means for assigning a given transmission channel to one of the extras if some part of one channel malfunctions.

For each selection matrix, scanner, stepping switch, or multiplexer, a full duplicate will be provided.

Figure 4.3.2.2-1 represents a preliminary functional block diagram of the display selection and driving equipment.

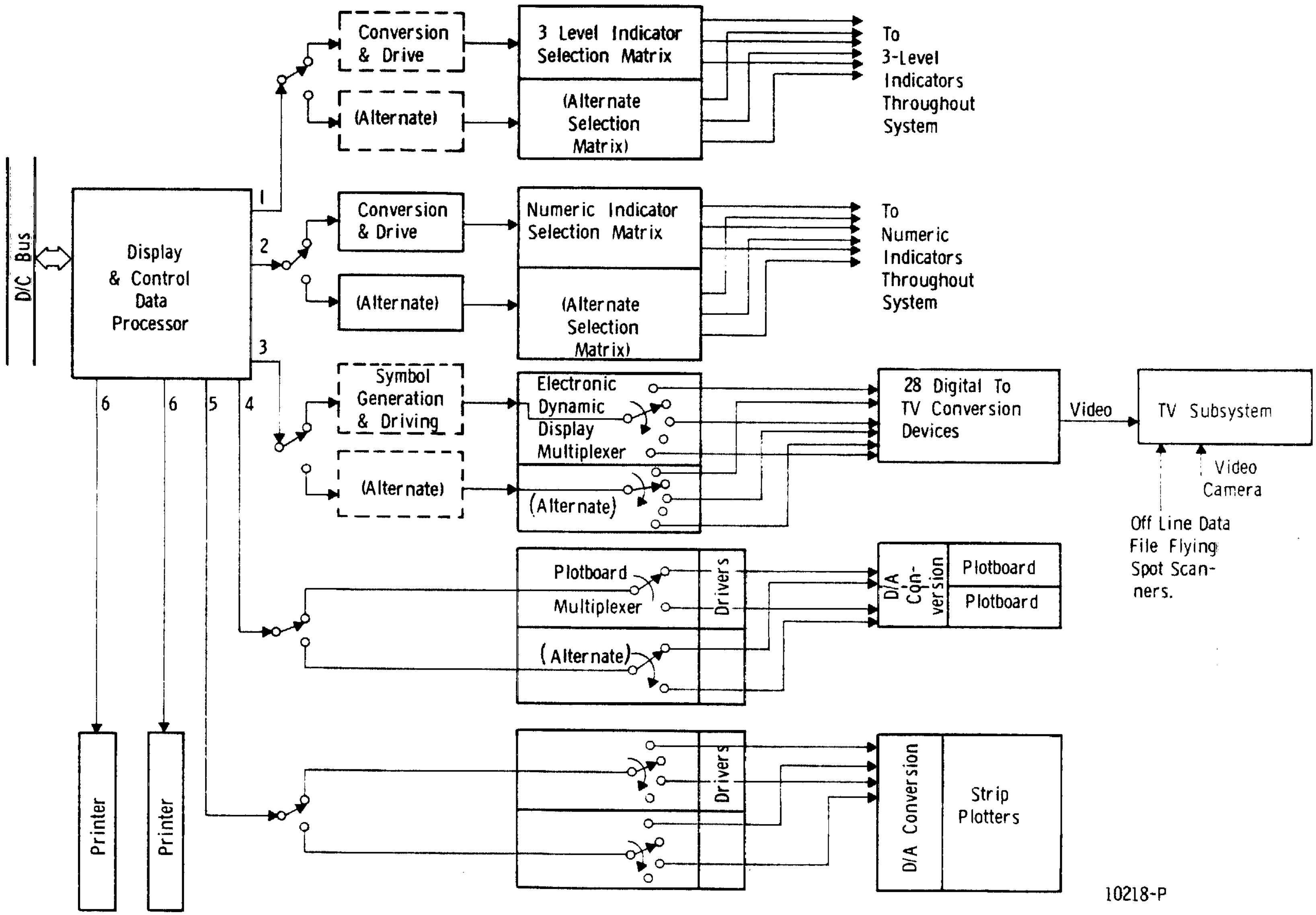


Figure 4.3.2.2-1 Display Selection and Driving Equipment Block Diagram

4.3.3 System Considerations

4.3.3.1 Computer Inter-Communication Speeds

Computer systems can be described as either off-line, on-line, or real-time systems, with respect to the timeliness of data input and output requirements.

In off-line data processing applications, the basic input and output operations will change depending upon the job to be done. For example, business data processing is characterized by a relatively large input-output requirement relative to the transform function, while scientific data processing is generally characterized by relatively complex transform functions and relatively small input-output functions. In these off-line systems, the data output is essentially the final step of the processing and is printed or stored on magnetic tape. In some cases, however, the results of the computer operations (its output) is the input for a second computer.

In these cases, the computer communication to the additional computer is via core, drum or magnetic-tape memory. The computer communicates with other computers by transforming this data to a form acceptable to the second computer. Figure 4.3.3.1-1 indicates three general techniques for transferring data automatically or semiautomatically from one computer to another for off-line systems. Figure 4.3.3.1-1a indicates the transfer method via a drum unit containing essentially dual-drum control (read-write) units which allow computer A to write on the drum and computer B to read off the same drum, asynchronously; i.e., computer B can obtain the information that computer A puts on the drum whenever computer B desires it. Note that in this system, there is no indication to computer B that any data has been put on the drum by computer A. Figure 4.3.3.1-1b indicates a tape-to-tape transfer which is similar to the drum transfer technique. Figure 4.3.3.1-1c indicates a semi-automatic method in which data is stored on one magnetic tape and hand carried to another magnetic tape, each magnetic tape being associated with a different

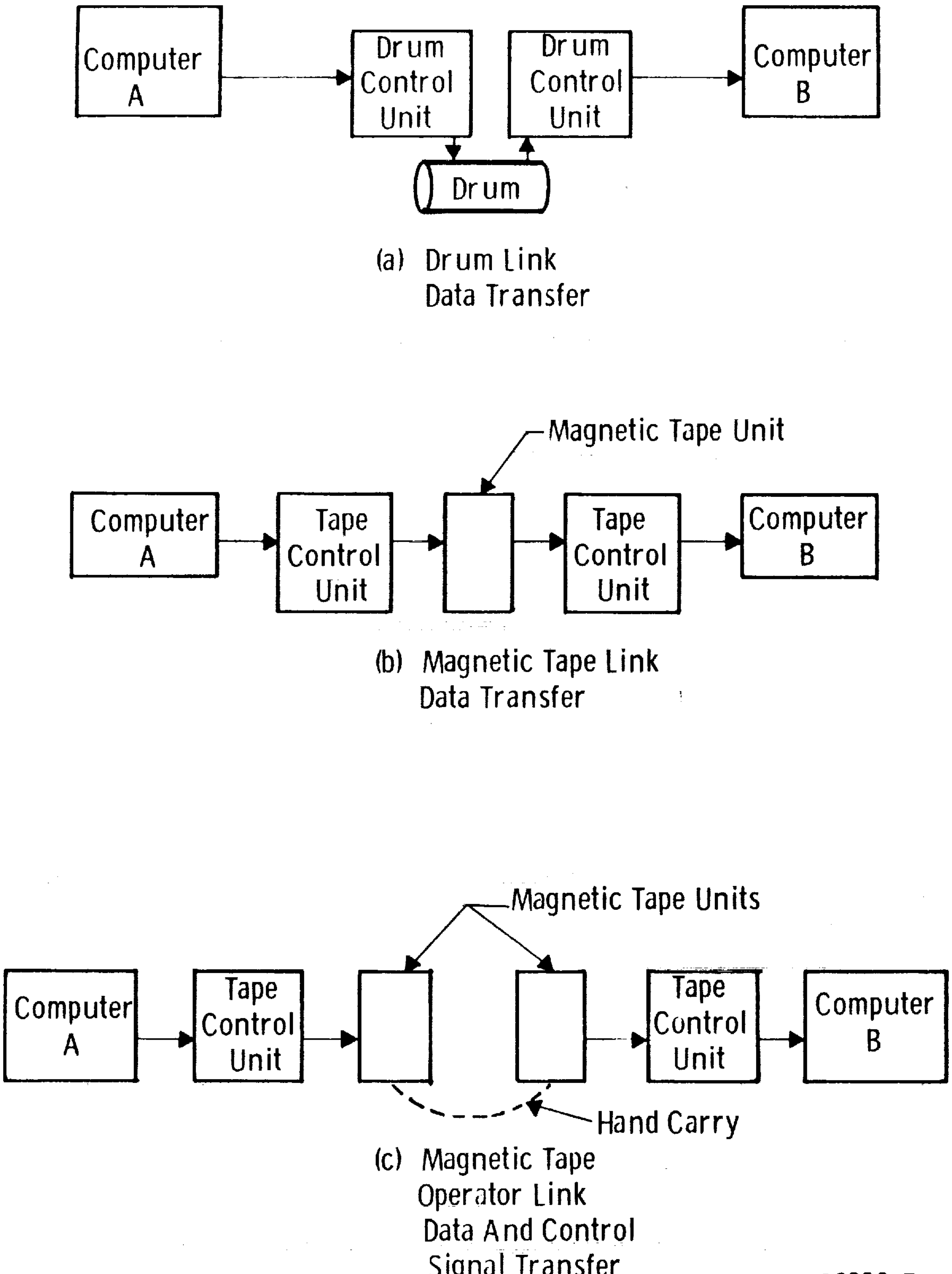


Figure 4.3.3.1-1 Indirect Computer Intercommunication

computer. In this case, the operator, who hand carries the data tape, can alert the second computer that the data is available for processing.

When system requirements dictate the application of more than one digital computer to handle an on-line, real-time, or near real-time data processing load, high-speed, automatic, bi-directional inter-communication between digital computers is generally a necessity. The methods shown in Figure 4.3.3.1-1 are not satisfactory. Most large-scale computers presently available can perform this function, although each does so by different techniques which generally require additional equipment. The method best suited to a particular system application must be determined from the data processing requirements and specifically from the processing load and the computer system organizational requirements.

Successful inter-communication between computers in a real-time mode requires that sufficient communication channel capacity and speed, as well as appropriate control signals, be available to both computers. The former requirement comes from the data processing requirements and the computing system organization. The latter requirement comes from the internal design of the computers. In actual practice, as will be shown, the latter requirement is generally the more difficult to successfully implement.

4.3.3.2 Computer Inter-Communication Methods

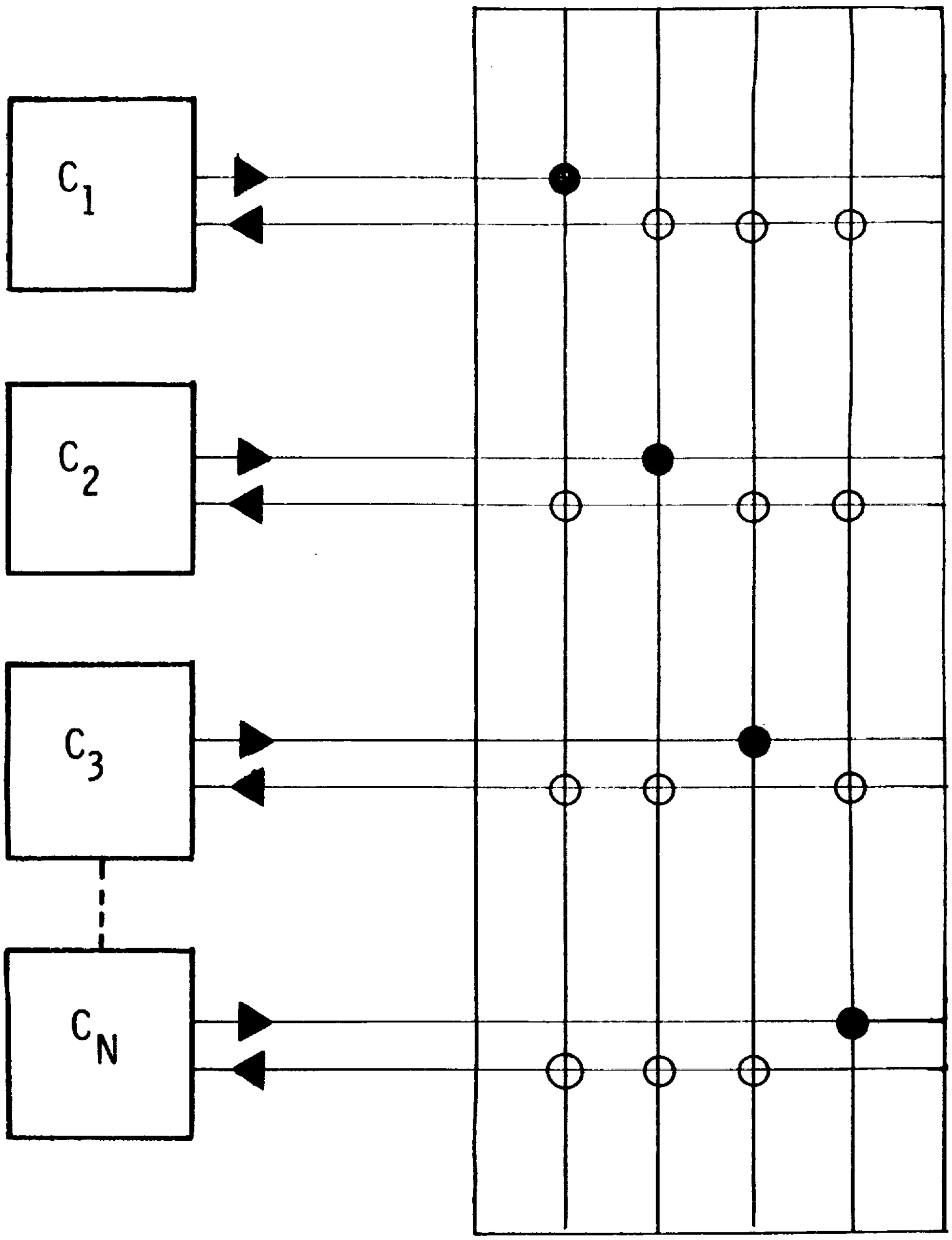
The nature of the Apollo-Gemini data processing requirements and of the IMCC, are such that the data processing tasks can be divided among several computer systems, if desired. The requirements for dividing these tasks stems from two basic factors, growth and reliability. The desire to allow for growth of the system necessitates the modular approach to the data processing problem so that incremental increases in the processing requirements can be met by corresponding incremental increases in computing capability. An on-line system, such as proposed for the IMCC, also requires the full application of spare computer capabilities to provide the reliability required.

Given the nature of the problem and a requirement for modular computer subsystems, flexible computer intercommunication capabilities are required to ensure cooperative operation of the data processing complex. Specifically, each computer system must have the capability to communicate with each other computer system to allow the flexibility of growth, reliability and efficient operation.

a. Central Exchange. The most flexible and the most costly intercommunication subsystem is a central exchange system. The central exchange is a high speed intercommunication switching unit similar to a telephone switching exchange. The exchange performs the important function of switching different computers to other computers at rapid rates, allowing a flexible intercommunication pattern to be dictated by the requirements of the individual computers and the processing system. There is no time sharing requirement in this system, and each computer may access any other device if that device is not busy. The exchange offers a completely isolated system in the sense that each computer is isolated from all other computers and not able to directly affect the operation of those other computers unless desired by both computers. The basic disadvantage of the central exchange is its high cost to perform the flexible switching. Figure 4.3.3.2-1 indicates the functional application of an exchange, in which any computer may talk with any other computer.

   There is the capability for the central exchange type communication system to grow beyond the planned capability of one exchange. In this case, an additional exchange can be connected to the initial exchange via one or more trunk lines, such as the telephone system does. The additional modular exchanges need not be as the original exchange and can be planned for that size which is consistent with the problem requirement.

b. Data Bus. A somewhat less flexible intercommunication system which retains the capability of intercommunication of all devices but gives up the complete freedom of intercommunication by time-sharing the communication paths, is a data bus. The data bus is a straightforward system in which all computers share a common communication path with all other computers. One proposed type of data bus, as shown in Figure 4.3.3.2-2, allows all computers to continuously listen on the bus, but only to talk on the bus at the discretion of a control unit within the bus, which commutates or selects among the different input devices in a time-sharing manner. The bus system has the basis advantage of being at the same time relatively flexible and moderately priced.



NOTE:

● PERMANENT ACCESS TO REQUEST CONNECTION

○ ALLOWABLE CONNECTIONS UNDER DISCRETION OF CENTRAL DATA EXCHANGE

10341-P

Figure 4.3.3.2-1 Central Data Exchange

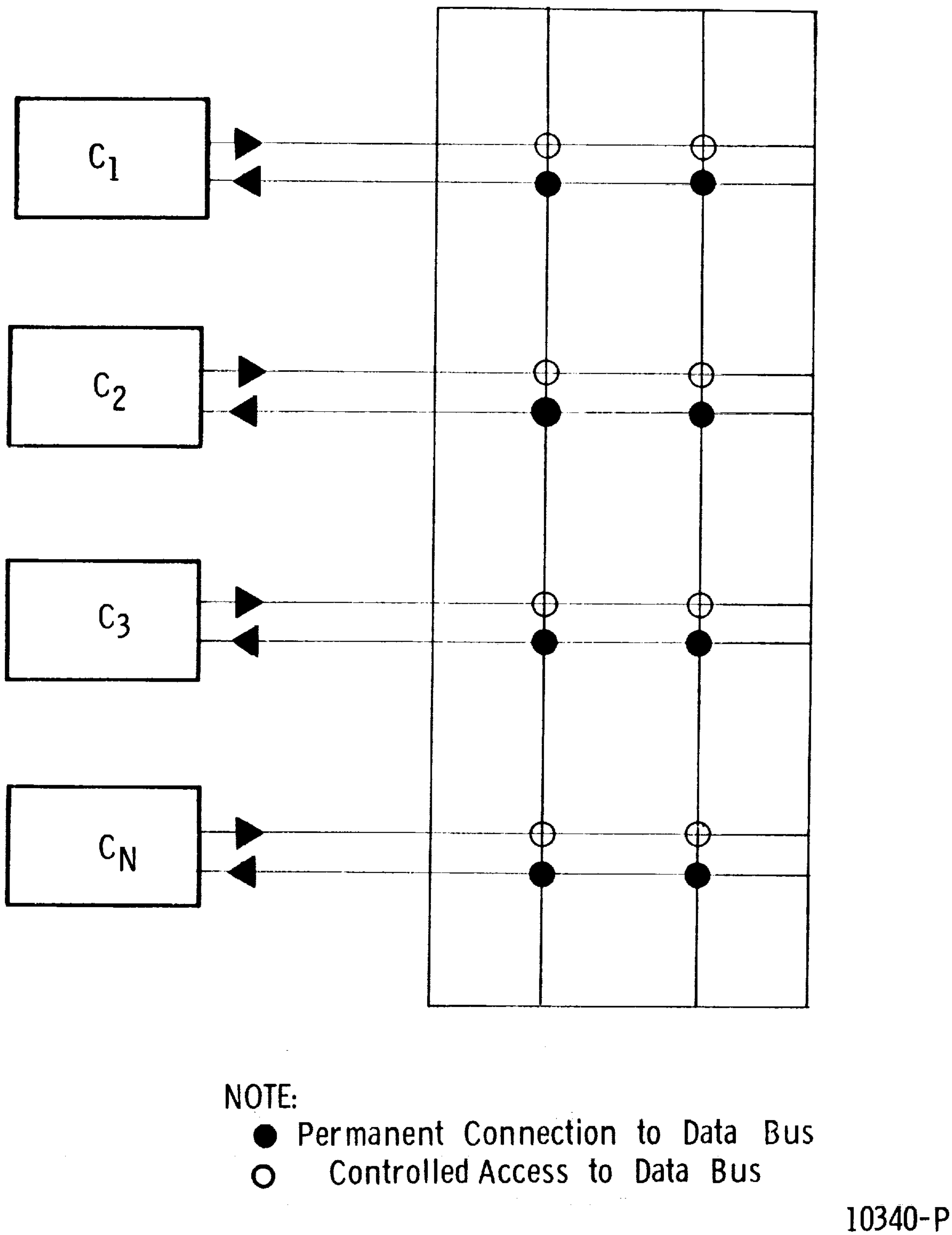


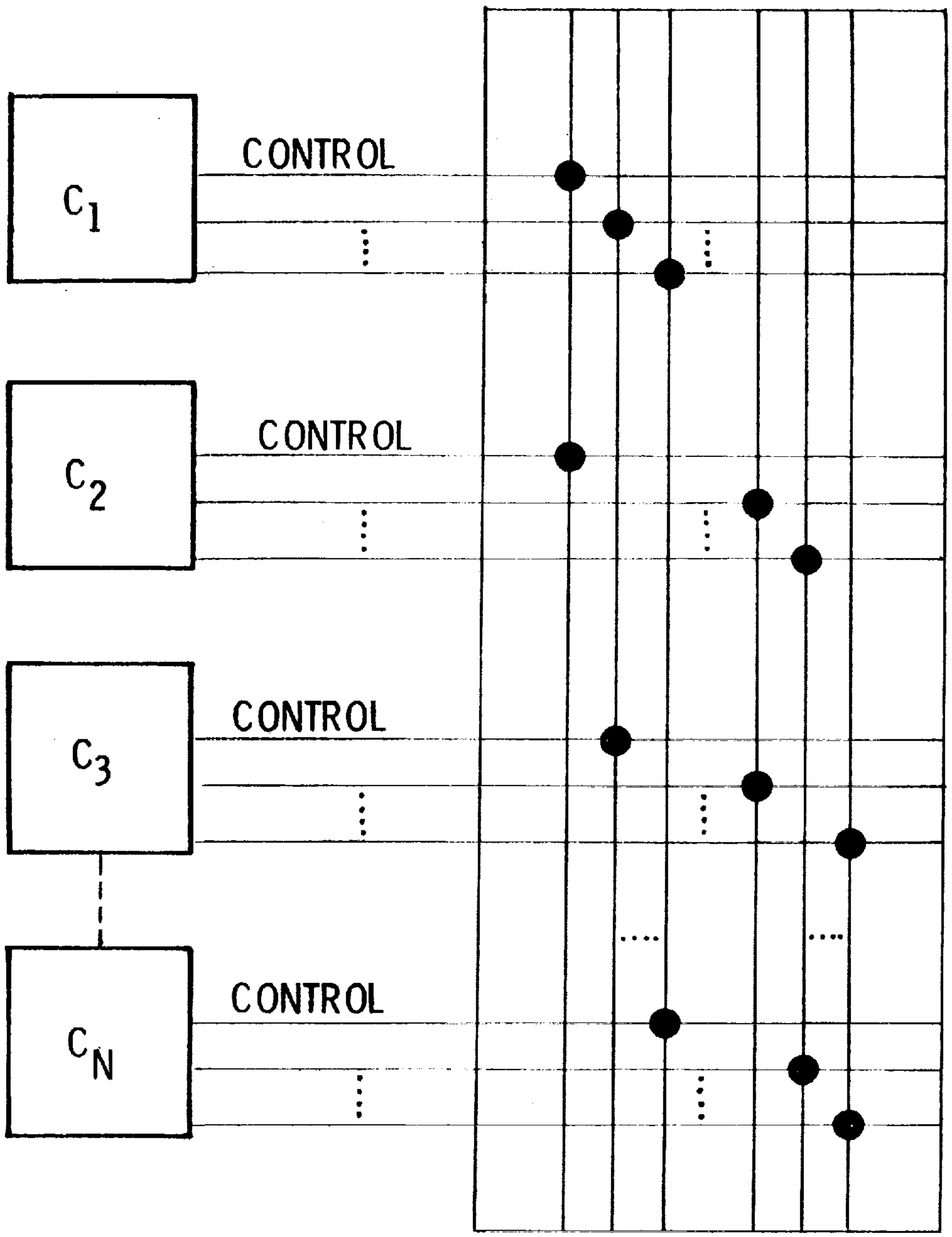
Figure 4. 3. 3. 2-2 Data Bus

That is, any number of computers could be tied on the line as long as the time-sharing requirement was not a restriction. The queuing problem must be investigated to determine whether one bus line, two bus lines, or more are necessary in any proposed configuration.

c. Direct Connection. The third type of intercommunication system is a direct wire-to-wire communication system in which all computers are directly tied to all other computers as shown in Figure 4.3.3.2-3. The advantage of such a direct wire system is the reduction in the extra equipment required, no time-sharing requirement, and a complete isolation of intercommunication paths between devices. The system, however, has the two disadvantages of requiring many input-output lines from each computer and a relatively non-versatile system in the sense that when a larger number of computers are required to intercommunicate, the number of lines and I/0 connections required at each computer is increased proportionally; (N-1) lines are required from each of the N computers required to intercommunicate. However, the direct system in large-scale computers has an advantage of being readily implemented via existing hardware techniques.

d. Summary. In summary, then, the exchange offers a relatively high-speed, high-cost, highly-versatile intercommunication system. The bus system offers a high-speed, moderate-cost, time-shared, intercommunication capability. The direct connection offers a high-speed, moderate-cost, rather cumbersome intercommunication capability. The required amount of intercommunication and the transfer rate necessary in the processing system will dictate the optimum method. If, as is expected, there is no requirement for an ultra-high-speed switching and data transfer rate, such as one computer talking directly with another computer at the rate of a couple of hundred thousand words-per-minute, then a direct tie system or a bus system will be most useful, depending upon the number of computers required. If a small number of computers are envisioned for example, three or four, a direct-tie system is probably the most economical. If a larger number of computers, such as five to ten, are required, then a bus system should be investigated. A larger number of computers than this, or higher speed requirements than those stipulated, might necessitate a high-speed data exchange system.

In addition to the three generic systems discussed herein, any combination of these systems could be utilized in a "mixed" operational data intercommunication system. The use of a mixed system can make sense wherein the system requirements do not justify a central exchange and yet indicate that a single data bus may be insufficient. In such a



NOTE:

● All connections permanently made
\+ No other connections required
... Multiple data lines

10339-P

Figure 4. 3. 3. 2-3 Direct Connection

case, for example, two or more data busses could be utilized with an exchange type switching among them. Another example is a direct connection system, in which, due to the nature of the problem, it is recognized that one computer will never want to talk to two other computers at the same time, and a bus could be arranged between those two computers such that one computer could have the capability to talk to either one but not both.

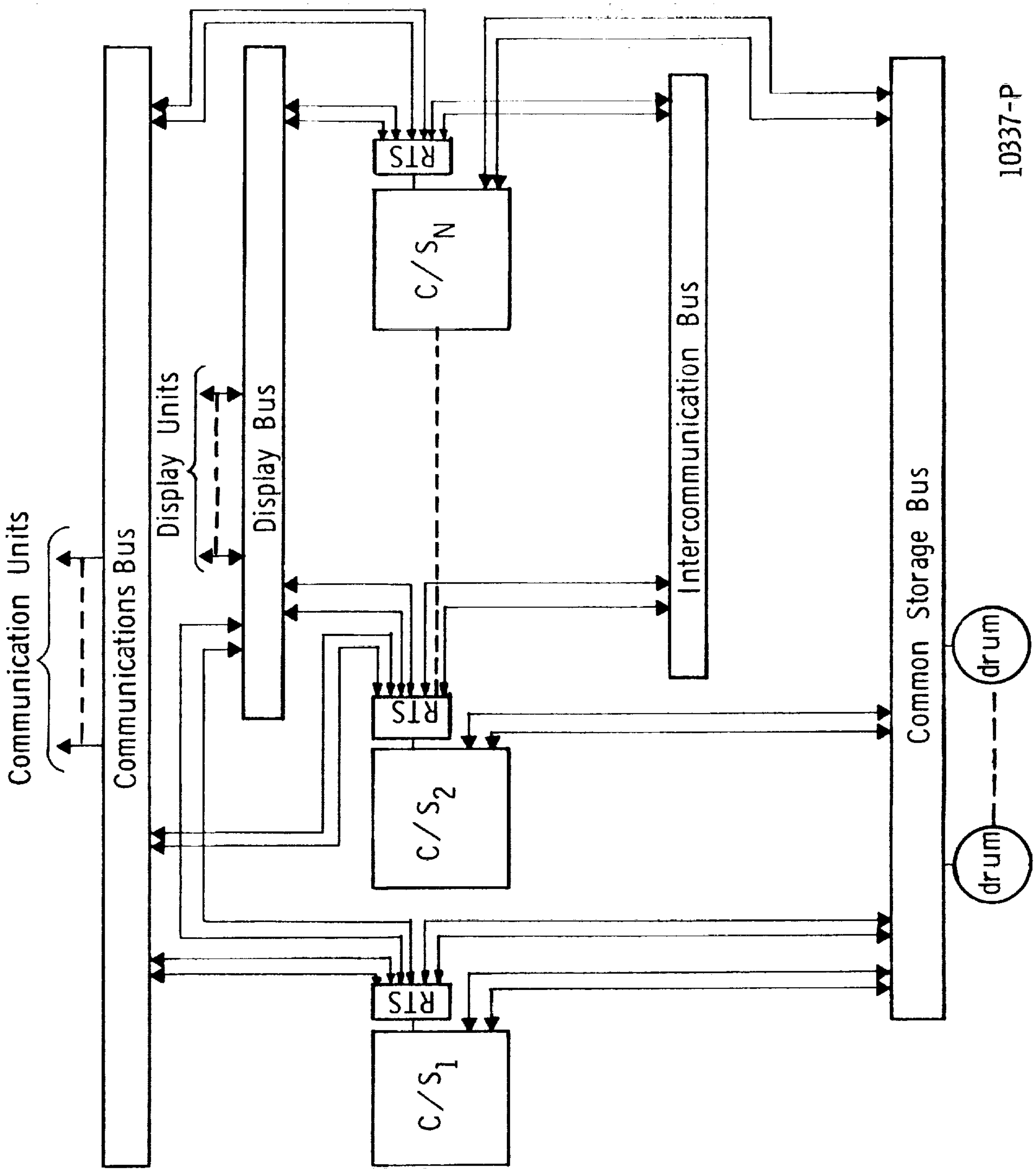
4.3.3.3 Computer Connections Using Data Busses

In this Section, brief descriptions are given of the means for organizing intercommunication among a large number of computers using data busses.

The system organization using busses for communication among the computers is detailed in Figure 4.3.3.3-1. In this figure, there are four busses for the transmission of data. The four busses are used to connect: (1) the computers to the external communication system; (2) the computers to the displays; (3) the computers with common storage; and (4) computers directly with other computers.

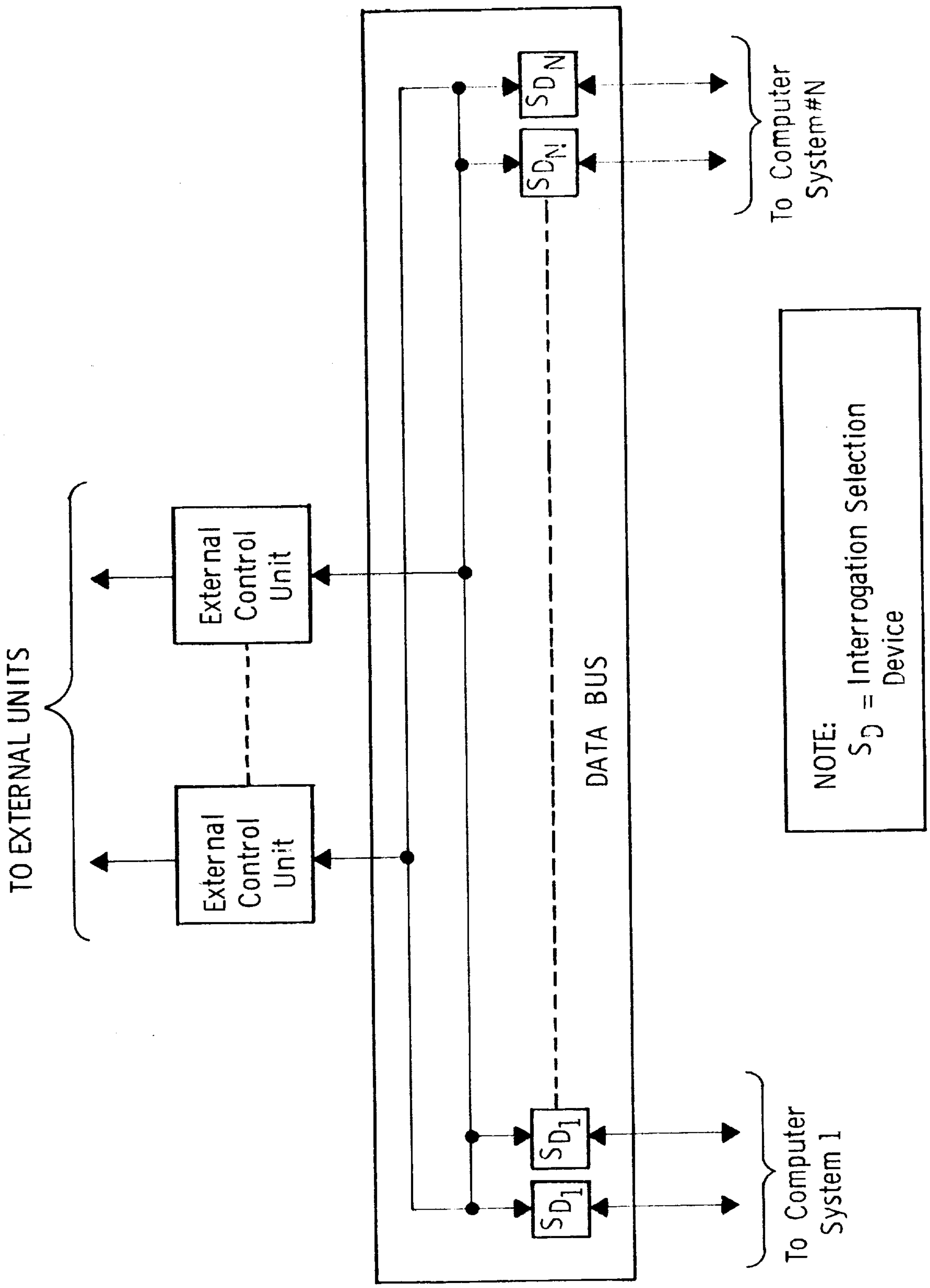
The computers are not permanently attached to the busses. In fact, the computers are attached to particular busses by means of a manually-operated plug board. In normal operations, the plug-board connections are not altered during a mission. Even when a computer fails, it is not necessary to employ the plug board to bring a new computer into use. The plug-board connections have to be altered only when it is desired to disconnect a computer or to attach a new spare computer to one of the data processing systems. The detailed requirements for each are shown in Figure 4.3.3.3-2.

In using data busses for communication with external devices, it is assumed that each control unit is equipped to recognize its own address when it appears on the data bus, and is ready to accept any data transmitted to it. The computer transmitting on this bus will not wait for an acknowledge signal from the external device. As a consequence,



10337-P

Figure 4.3.3.3-1 Multi-Computer Organization Using Data Busses



10338-P

Figure 4.3.3.3-2 Data Bus Connections to External Units there is no queueing problem associated with this bus, since each computer's transmission access to a bus is under commutator control.

There is a comparatively large number of different devices used for communication with the external world. One method to implement the required communication is to employ a data bus for communicating with all of these external devices, and endow each external device with the capability to recognize when it is being addressed by a computer. In order to read out to a communication device from the computer, the data is placed on the communication data bus along with the address of the external device, which then accepts the data.

In order to accept data from an external communication device, the computer is interrupted through an interrogation selection device, marked S_D, on each line. These interrupt signals from the external devices, stating that they have data to be read into the computer, allow an asynchronous mode of communication.

The intercomputer communication busses are shared by all computers attached to the bus. Each computer transmitting data should first transmit the address of the computer that is to accept the data.

For the amounts of data to be transmitted, queueing does not appear to be a problem.

a. Advantages. The advantages of using common data busses are the following:

1. The number of computers in the system can easily be increased or decreased without having to add or delete a significant amount of communications equipment, and without complicating the communication relationships among the various devices in the system.
2. Any of the computers may be associated with either MOCR, any computers may be associated with either set of displays, and any computers may communicate with the external world.
3. Except for communication with the external communication system, the data processing equipment associated with each MOCR can be physically and electrically separate from the equipment associated with the other MOCR.

4. By simple changes in plug board connections, any computer can take on any function in either MOCR. This leads to better system reliability.

5. The concepts of communication among parts of the Data Processing System are simple to understand.

b. Disadvantages. Some of the disadvantages of the use of data busses are the following:

1. There may possibly be a queueing problem. This is not believed to be the case because of the comparatively small amount of data to be transmitted, because there is no requirement for high speed transfer of data and because it appears that it is possible to program around the queueing problem.

2. It may be suggested that the data bus can hang up, preventing any communication at all between computers if one computer fails and does not send an acknowledge signal in response to data transmitted to it. It is possible to get around this problem both by the use of suitable hardware and by computer programming.

3. Since any computer can have any function in this Data Processing System, it is necessary for each computer to have the same auxiliary equipment available to it as is available to any other computer. This equipment might include tape units, flexowriters, drums, etc. With the computer systems of some manufacturers, such separate auxiliary equipment would have to be provided for each computer. It would seem, although it has not been investigated thoroughly, that the amount of such auxiliary equipment that would normally have to be associated with each computer, even without this system constraint, would be not very different in cost. Another possibility, if this is not so, is that it may be possible also to switch these auxiliary equipments from one computer to another. This requires further investigation.

4. All data is sent via one path. There are no alternate paths provided between the same units.

5. If the data bus itself fails, which is not too probable because of its simplicity, all intercommunication between certain units will cease.

4.3.3.4 Computer Connections using Direct Connection

The second data processing system organization assumes a limited number of direct computer-to-computer communication channels via a plug board, and a limited number of computer-to-input/output buffer connections via the same plug board. Two input-output buffers are associated with each display system, and two input-output buffers are used between the computers of each MOCR and the external communication system. In the event of failure of any device, computer or input-output buffer, alternate communication paths exist, and still further alternates can be established by plug board operations. See Figure 4.3.3.4-1 for a typical system with its interconnections.

a. Advantages. The advantages of this system are:

1. It provides direct communication between devices without the use of busses and their attendant disadvantages.
2. The number of computers in the system can be increased or decreased without great expense or complication in communication.
3. The equipment associated with the two MOCR's can be electrically separate.
4. It uses only a small number of input-output buffers.
5. By changing connections, any computer can perform any function in the system.

b. Disadvantages. The disadvantages of this arrangement are:

1. Hardware must be provided for each intercomputer communication path, although not much more than for the data bus.
2. In case of a computer failure, it may be necessary to route data to display devices or the external communication equipment by a round-about path until new plug board connections are established.
3. The plug board status is not immediately apparent at any instant.
4. It is not known whether it is possible to switch input-output buffers among computers through a plug board in the fashion described, or whether this would require a small amount of engineering or a large amount of engineering.

4.3.3.5 Multi-Computer System Organizations

a. Problem. This section looks at the problem of organization and inter-communication of multiple computer systems to solve real-time data processing problems. The section describes a method of looking at computers and communication problems, a method of looking at organizational problems, and details the possible system configurations utilizing these methods.

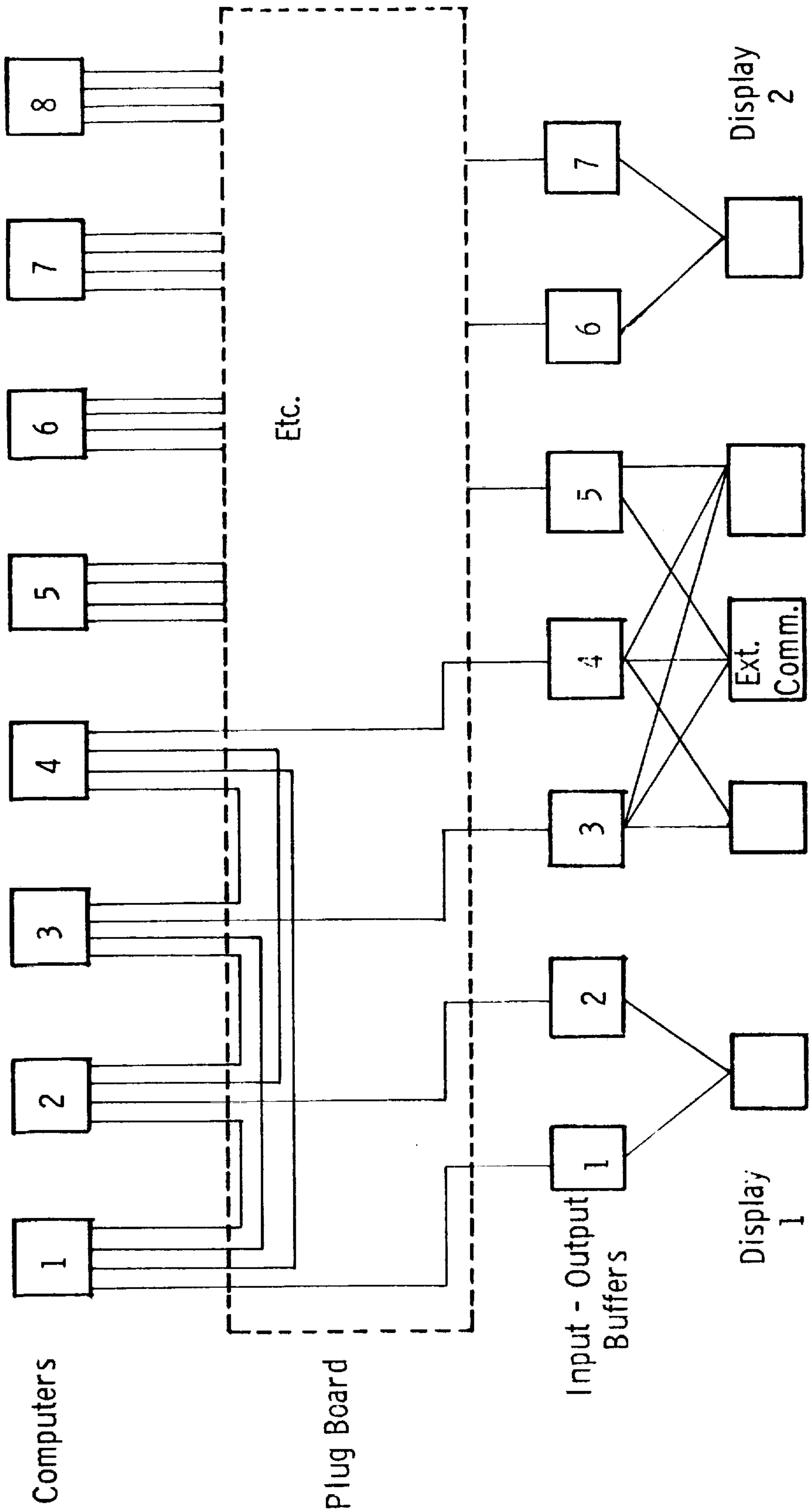


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Figure 4.3.3.4-1 Multi-Computer Organization Using Data Busses

A computer system can look like a black box. See Figure 4.3.3.5-1, in which the function of the Computer System is to accept an input, process or transform that input, and produce some output. It is assumed in this discussion that the box labeled "computer" contains not only the main frame computer, but all important auxiliary equipment associated with the computer; for example, magnetic tapes, drum storage, peripheral, or other units. The time required from accepting the input to producing the output is called the "throughput" time. In a real-time system, this throughput time is a critical parameter, An additional critical parameter in a real-time computer system application is the input and output capacity and speed. These quantities are measured in terms of channel capacity and response time. In designing a real-time, multi-computer system, these parameters are of prime importance.

Computer intercommunication is concerned with the speed and amount of data capable of being transferred from one computer to another. All computers require a special input-output buffer control unit to control the transfer of information from the computer to somewhere else. In normal computer operations, this input-output unit controls the transfer or reception of information from magnetic tapes, paper tapes, punched cards, and other devices. When the transfer rate approaches the computer rate, a special input-output buffer generally called a Data Transfer Control Unit (DTCU) is required. In high-speed, intercomputer communication, one such control unit is required for each input-output channel to be utilized in the computer. In the slower speed devices, one DTCU can be used to operate many devices simultaneously. The basic information transferred in any computer-originated transfer are control signals and data. The control signals must precede the data to be transferred. Before the transfer can occur, the user of the data must indicate it is ready and capable of receiving the data. When these signals have been communicated, the data flow begins. All data transfers of high or low speed occur in roughly the same fashion.

b. System Organizations. The IMCC data processing functions can be handled by a computer system organization of from four to ten computers interconnected by data busses, direct wires, or a central exchange. The organization of an IMCC utilizing any one of these large scale computers will be detailed herein.

An on-line computer system accepts input data from the external world via the communication unit. The information is accepted through an input-output buffer (IOB) into the computer complex. The data is processed, and those outputs to be used for display purposes are transferred to the input-output buffer, which coordinates and drives a display buffer and the displays. A computer complex refers to more than just a computer. Included in the complex will probably be at least one additional input-output buffer, several magnetic tape

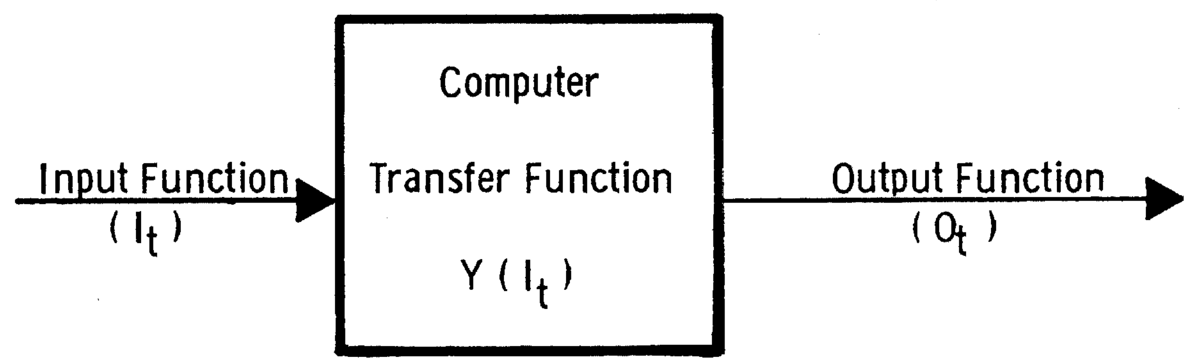


Figure 4. 3. 3. 5-1 Computer Transfer Function

units, a drum unit, and other peripheral equipment necessary to operate each computer complex. Figure 4.3.3.5-2 indicates the general composition of a computer system in block diagram form. The auxiliary equipment associated with each of the complexes is not shown in other figures.

In the normal operational mode, the simulation computer can also obtain some information from the external stations via the communication unit. In addition, the Simulation System has its own set of display units. These display units are directly under the control of the simulation computer and are physically and electronically separate from the real-time displays.

The spare computer plays a very important role in the IMCC system. In fact, the word "spare" is perhaps a misnomer, for the "spare" computer is not at all a spare. The "spare" computer is charged with the responsibility of taking over the function of either the real-time system or the Simulation System upon any failure. In order to carry out this function, the "spare" computer will continuously monitor and check the operations of the real-time and simulation systems.

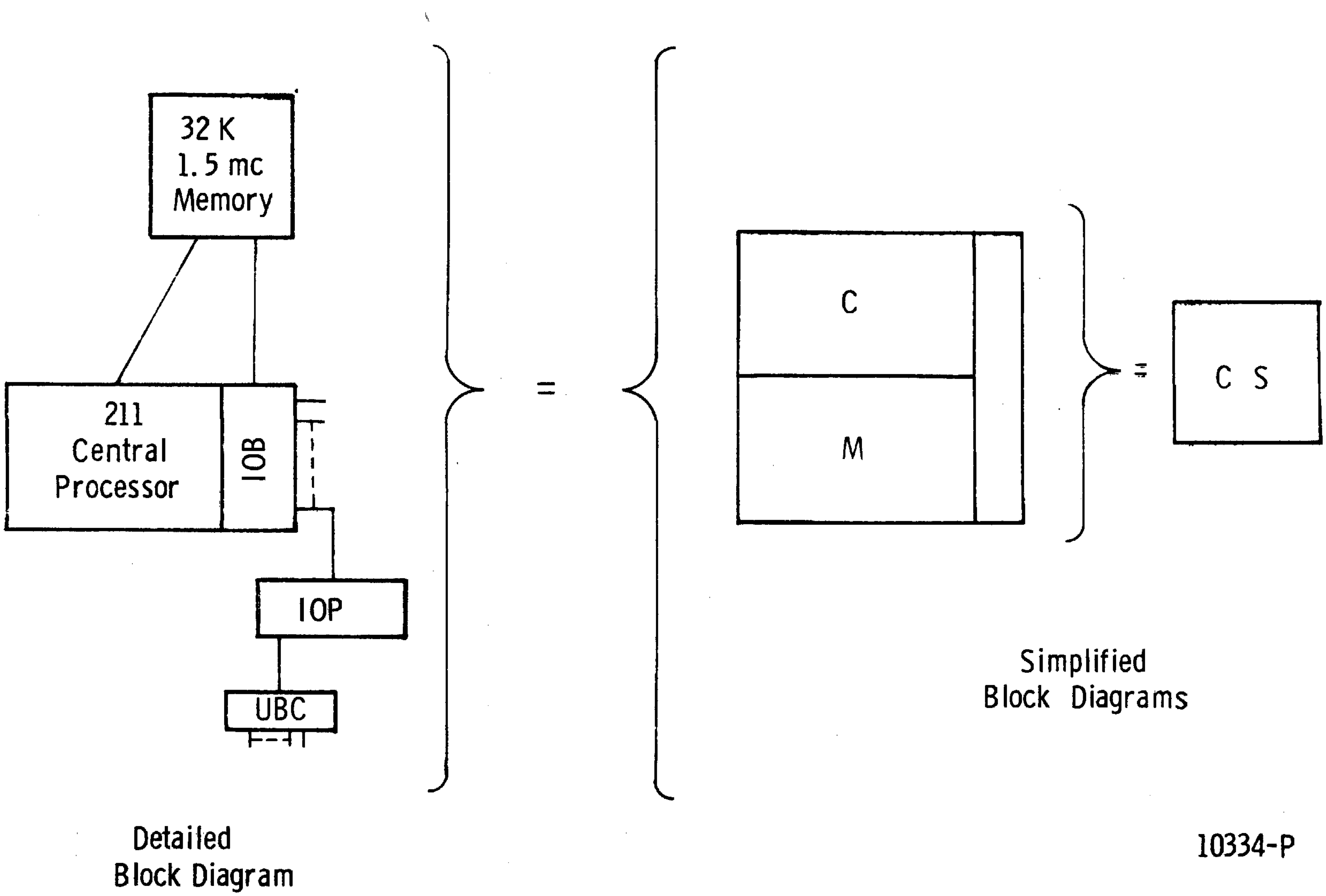


Figure 4. 3. 3. 5-2 Generalized Block Diagrams of Computer Systems

4.3.4 Equipment Considerations

4.3.4.1 Available Large-Scale Computing Systems

This section details the general organization of several large-scale computer systems which have been considered for implementation of the IMCC data processing tasks. The diagrams show the input-output intercommunication capabilities of the various systems.

a. CDC1604A

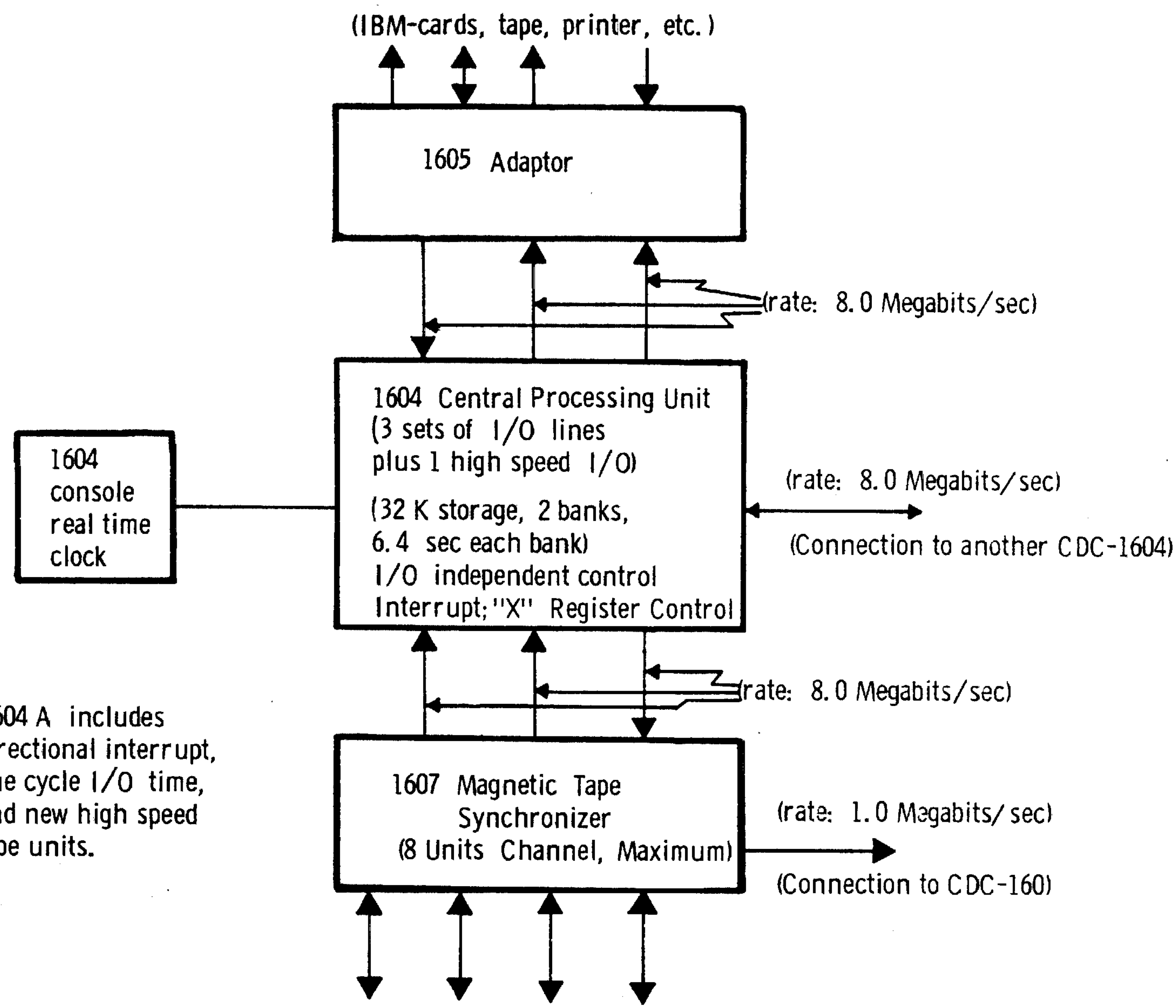
Figure 4.3.4.1-1 illustrates the CDC 1604A computer. The 1604A computer has a direct channel connection to an additional 1604A from the central processing unit. This channel and its appropriate control lines facilitate data transfer directly at the rate of eight megabits-per-second or approximately 200,000 words-per-second. Only one of these channels are available on each 1604A computer. However, alternate communication can be set up at lower transfer rates using it to connect to a CDC1604A satellite computer.

b. CDC3600

Figure 4.3.4.1-2 indicates the general organization of the CDC3600 digital computer. This computer can communicate with other computer modules either directly or through a buss or exchange via Model 3605 data channels. These data channels serve the dual purpose of alerting the computer so that information is available to be transferred, and of coordinating the actual data transfer. Once control signals are intercommunicated and accepted, data may be transferred from one computer module to the other at the integral speed of the computer modules (namely, 48 megabits-per-second). Data could also be transferred to a second computer via the memory and communication modules at a slower rate.

c. IBM-7090 and 7094

Figure 4.3.4.1-3 indicates the general organization of the IBM 7090 and the IBM 7094. This computer system has the capability of communicating directly with another computer via the IBM 7607 data channel and the direct data connection unit. The direct data connection unit permits high-speed data transmission between computer units at the rate of 150,000 words-per-second. Data coordination and control is via one or more of the ten input and ten output sense lines that are under direct program control in each computer. So that transfer of data between computers may occur, one channel must be connected to the direct data connection unit. All control signals will be controlled through the 7607, even



NOTE: (1) 1604 A includes directional interrupt, one cycle I/O time, and new high speed tape units.

10342-P

Figure 4.3.3.4-1 General Description of CDC 1604A(1)

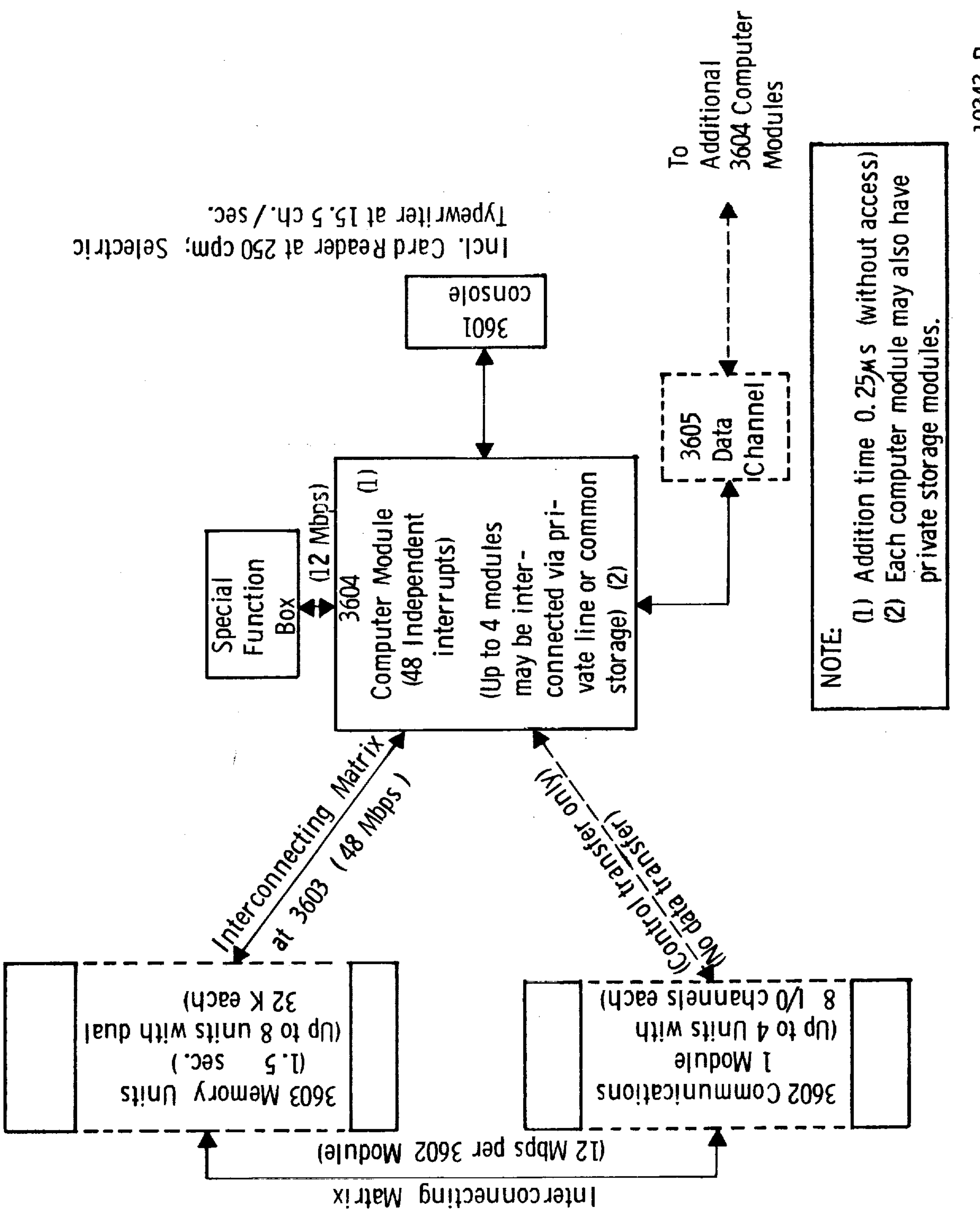


Figure 4.3.4.1-2 General Description of CDC 3600

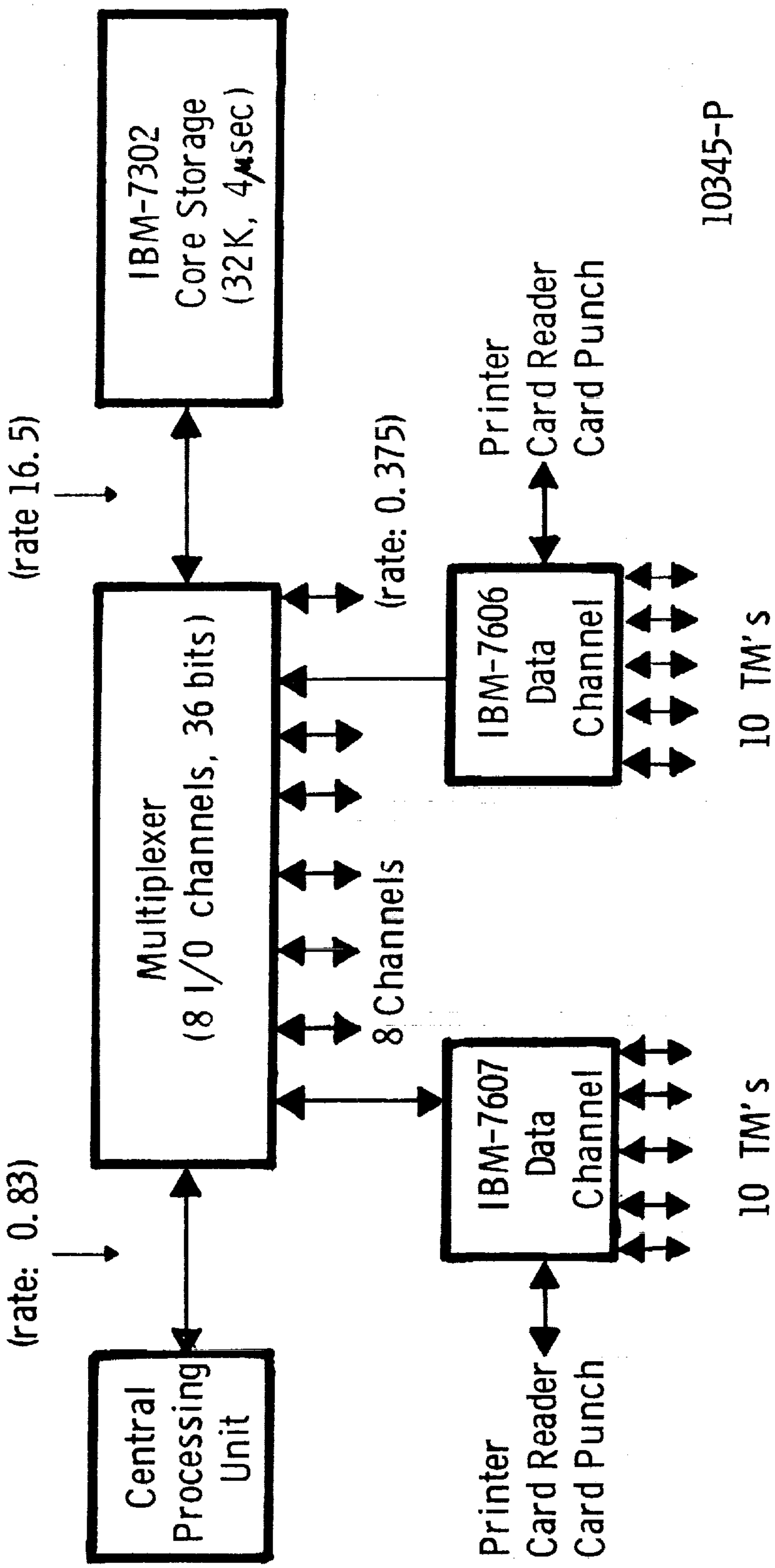


Figure 4. 3. 4. 1-3 General Description of IBM 7090 and 7094

though the data will be directly transmitted through the direct data connection unit. The 7607 utilized for this function does not require that additional units be connected, but is handicapped in that the card reader station allocated on each 7607 is utilized for the direct data communication unit control signals. In addition, a special core memory file of 98,000 words can also be connected to the direct data channel of either computer and accessed as an auxiliary memory.

A slower automatic communication technique would be via the 1301 disk file, which allows a transfer rate on the order 90,000 words-per-second. This unit connects to one of the eight direct multiplex channels and is available to both computers. However, control signals are not transmitted, and the second computer must search continuously for the data.

d. Philco 211 and 212

Figure 4.3.4.1-4 is a general description of the Philco 211 and 212 computers. These computers feature asynchronous central computing functions and overlapping memory units. Computer communication with external units is controlled by the input-output buffer (IOB). The 211 system IOB has three channels, one of which accepts multiplexed data from eight remote units. The multiplexer is a standard Philco real-time control unit. The 212 system IOB has eight high-speed channels.

e. Rem Rand 1107

Figure 4.3.4.1-5 indicates the general organization of the Univac 1107. This computer features computer-to-computer tie through an auxiliary inter-computer control unit. The direct data transfer is similar to the IBM direct data channel unit. The inter-computer control unit indicates via interrupt lines, to either or both computers, that data transfer is desired. Once the appropriate control signals are initiated, the data transfer rate is at a speed of 200,000 words-per-second.

4.3.4.2 Computer Loading

The basic data for the initiation of the computer loading estimates contained within this report are derived from manufacturers' published information, which has been carefully checked for consistency among manufacturers. One of the major problems in utilizing manufacturers' data comes from their estimates of the average computing speed of their machines. It is important to note that the average arithmetic speeds utilized herein reflect the average time to perform the listed

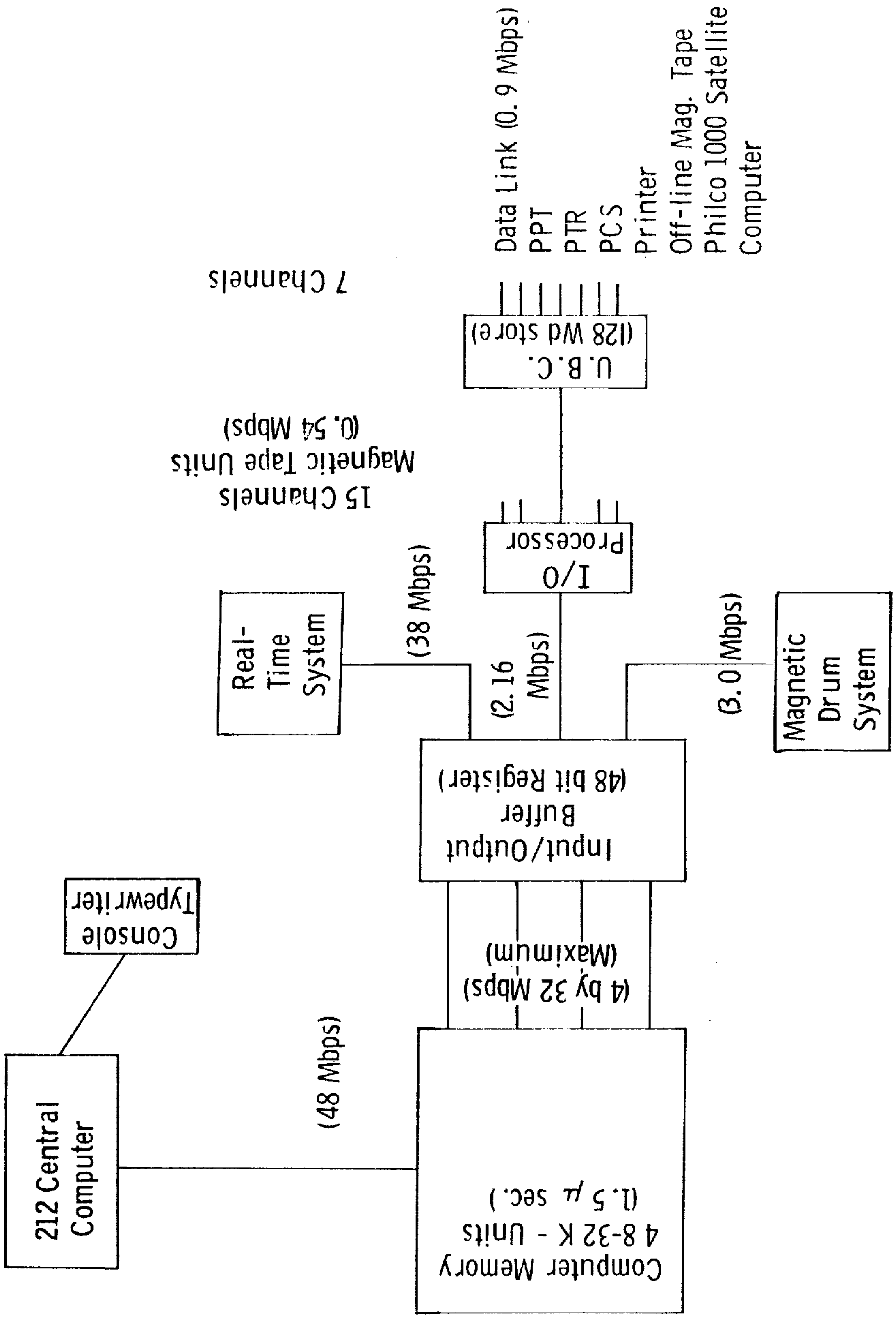


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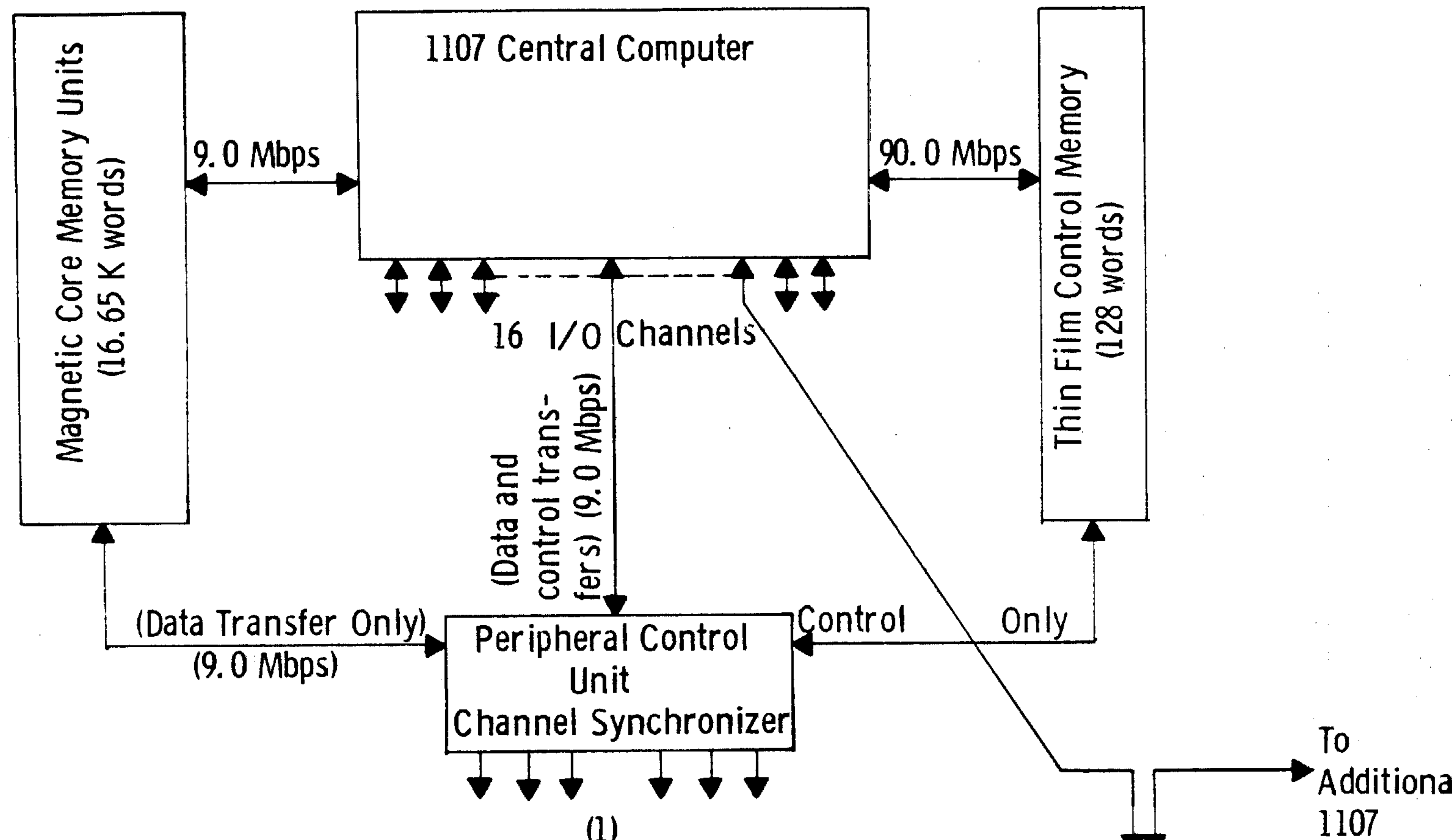
Figure 4.3.4.1-4 General Description of Philco 211 and 212



(1) Peripheral Equipment and Transfer Rates
- a. FH 880 Drum, 2. 13 Mbps
- b. Magnetic Tape, 0.625 Mbps
- c. Printer, PDT, PTR, etc.

Figure 4. 3. 4. 1-5 General Description of Rem Rand 1107

10346-P

functions and do not reflect the capability of a completely overlapped memory or any sophisticated "look-ahead" features. Table 4.3.4.2-1 indicates the average arithmetic speed of the seven computers compared in this report. The average load factor, that is, the mix of fixed point and floating point operations, has been assumed to be 50% of each. This is an arbitrary breakdown, but appears to be a conservative estimate. Therefore, the manufacturers' average data for fixed point and floating point addition and multiplication are averaged to provide the effective arithmetic operation speed.

From the determination of the computing arithmetic operations required and the load requirements, the number of computers required to satisfy the program requirements can be calculated. The loading estimates for each task are measured in terms of the number of computations required per second of real time to respond to the system requirements.

The second step in the calculation of computing loads is to multiply the number of operations per second required for each function by the corresponding computation time. For example, Table 4.3.4.2-1 indicates that the Philco 211 has an average add time of 7.0 μsec and an average multiply time of 51.5 μsec. The time required by the 211 to perform the 8400 addition-type instructions associated with the flight dynamics program is 0.0588 seconds ($=8400 \times 7.0 \times 10^{-6}$), and the time to perform the corresponding 7170 multiplications is 0.370 seconds ($=7170 \times 51.5 \times 10^{-6}$). The computing times determined in this fashion for the computers of Table 4.3.4.2-1 are given in Table 4.3.4.2-2, "Interim Calculations."

The numbers in Table 4.3.4.2-2 are only interim results since they do not reflect the additional instructions required to actually implement the computations. For instance, to perform an addition in a computer, several instructions may be required: one to obtain the addend, one to obtain the augend and perform the addition, and one to store the result. The computing times indicated in Table 4.3.4.2-2 must be burdened to account for these overhead operations.

Table 4.3.4.2-1
BASIS FOR COMPUTING LOADING

Assume: 50% of Operations Fixed Point
50% of Operations Floating Point

		ADD (μs)	MULTIPLY (μs)
Rem-Rand 1107	Fix	6.0	14.0
	Flo	16.0	14.7
	Avg.	11.0	14.0
CDC 1604A	Fix	7.2	43.6
	Flo	18.8	36.0
	Avg.	13.0	40.0
CDC 3600	Fix	1.5	5.4
	Flo	3.4	5.4
	Avg.	2.5	5.4
IBM 7090	Fix	11.0	25.2
	Flo	14.0	24.0
	Avg.	12.0	25.0
IBM 7094	Fix	4.0	12.0
	Flo	6.0	10.0
	Avg.	5.0	11.0
Philco 211	Fix	2.1	43.0
	Flo	11.9	59.9
	Avg.	7.0	51.5
Philco 212	Fix	1.1	4.8
	Flo	1.8	5.1
	Avg.	1.5	5.0

The burdened times required to perform instructions are as indicated below. To perform a complete addition, the instructions needed are:

Obtain addend	T_A
Obtain augend and add	T_A
Store result	T_A
Total	$3\ T_A$

in which T_A is the time required for an add instruction. In like manner, the time required for a complete multiplication may be determined as follows:

Obtain multiplicand	T_A
Obtain multiplier and multiply	T_M
Store result	T_A
Total	$T_M\ (1 + 2\,T_A\ /\ T_M)$

in which T_M is the time to perform a multiply instruction.

Now,it is not always necessary to perform these complete sequences of instructions to carry out an add or multiply. On the other hand, there are often additional bookkeeping or administrative calculations that must be performed and which do not appear directly in a list of computations; these might include, for instance, address modifications or tallies. For this reason, the burden factors used here for addition and multiplication are 3 and $(1 + 2\ T_A/T_M)$, respectively. The quantity $(1 + 2\ T_A/T_M)$ is given in Table 4. 3. 4. 2-3 for the computers considered.

Using Tables 4. 3. 4. 2-2 and 4. 3. 4. 2-3, the fraction of a second required each second to compute flight dynamics, using a Philco 211, for example, is 0. 63 ($=0.059\frac{sec}{sec} \times 3.00 + 0.371\frac{sec}{sec} \times 1.27$). The

Table 4.3.4.2-2

INTERIM CALCULATIONS

Function	Number of Add (per sec)	Number of Mult (per sec)	CDC 1604 Add (sec/sec)	CDC 1604 Mult (sec/sec)	CDC 3600 Add (sec/sec)	CDC 3600 Mult (sec/sec)	IBM 7090 Add (sec/sec)	IBM 7090 Mult (sec/sec)	IBM 7094 Add (sec/sec)	IBM 7094 Mult (sec/sec)	Philco 211 Add (sec/sec)	Philco 211 Mult (sec/sec)	Philco 212 Add (sec/sec)	Philco 212 Mult (sec/sec)	Univac 1107 Add (sec/sec)	Univac 1107 Mult (sec/sec)
Network Control Vehicle Systems	6700	3000	0.087	0.120	0.016	0.016	0.080	0.075	0.034	0.033	0.046	0.155	0.010	0.015	0.074	0.042
Flight Dynamics	8400	7170	0.112	9.288	0.021	0.039	0.103	0.180	0.043	0.079	0.059	0.371	0.013	0.036	0.094	0.101
I/0 & Comm	9600	2400	0.125	0.096	0.024	0.013	0.115	0.060	0.048	0.026	0.067	0.124	0.014	0.012	0.106	0.034
Display, Operations Direction, Recovery Control	6500	6000	0.085	0.240	0.016	0.032	0.078	0.150	0.033	0.066	0.046	0.310	0.010	0.030	0.072	0.084

burdened computing loads for each of the computers are given in Table 4.3.4.2-4.

In this section, the computing load has been divided into four parts in such a manner as to minimize the necessary communication and program synchronization among computers.

In estimating the computing load, it is stipulated that no computer can be loaded more than 2/3 and be considered adequate to handle the tasks. Inaccuracies in estimates, and allowances for future growth make 2/3 a realistic cut-off point. Four CDC 1604s thus will not satisfy this criterion.

The IMCC data processing system can be implemented for each mission, without spares, using from one to four computers. A single CDC 3600 or Philco 212 can perform the entire data processing for one mission. Two IBM 7094s can do the same job. Four IBM 7090s, Philco 211s, or Univac 1107s can also be used for the entire data processing for one mission.

Table 4.3.4.2-5 indicates that the most critical loading occurs in the Flight Dynamics programs. These estimates are subject to question since the criterion utilized to estimate this load was the most uncertain of the entire loading estimates. It is possible to adjust these loading estimates by reviewing the accuracy desired in the analysis of the Flight Dynamics or by a more precise analysis and definition of the Flight Dynamics requirements.

Furthermore, it is possible that more sophisticated computational techniques now being developed on a research level could be instituted. It is also possible to split the Flight Dynamics loading by putting a part of the load in another computer. However, such action will increase the programming complexity. It is, therefore, felt that at this time these estimates are reasonably justified.

Table 4.3.4.2-3

MULTIPLICATION BURDEN FACTOR

COMPUTER	$1 + 2\,T_A/T_M$
CDC 1604	1.65
CDC 3600	1.93
IBM 7090	1.96
IBM 7094	1.91
Philco 211	1.27
Philco 212	1.60
Univac 1107	2.57

Table 4.3.4.2-4

SUMMARY BURDENED COMPUTING LOADS

(per mission support)

Function	CDC 1604	CDC 3600	IBM 7090	IBM 7094	Philco 211	Philco 212	Univac 1107
Network Control Vehicle Systems	0.46	0.08	0.39	0.17	0.34	0.05	0.33
Flight Dyna-mics	0.81	0.14	0.66	0.28	0.63	0.10	0.54
I/0 & Comm	0.53	0.10	0.46	0.19	0.35	0.06	0.41
Display Operatns Direction Recovery Control	0.65	0.11	0.53	0.22	0.53	0.08	0.43
TOTAL	2.45	0.43	2.04	0.86	1.85	0.29	1.71

Table 4.3.4.2-5

COMPUTER LOADING ESTIMATES

	Adds per/sec	Mult per/sec	Basic Cycle Time	Max Run	Remarks
Network Control					
a) Mission Monitoring	500	500	1 sec	1 sec	
b) Count down	No need to time		>1 day	Days	
c) Routine Diagnostics	1,000	500	1 sec	</sec	
d) GOSS scheduling (incl comm sched)	6	--	5 min	</sec	
e) Acquisition Info	200	30	5 min	3 sec	
f) Contingency extrapolations	1,000	500	1 sec	</sec	
	2,706	1,530			
Vehicle System					
a) Mission Monitoring (Telemetry)	2,000	---	1sec	</sec	Can be broken up but difficult to do so.
b) File sort & calc	500	500	unknown erratic	sec or minutes	
c) Vehicle Computer Backup	500	500	sec	</sec	
d) Contingency extrapolation	1,000	500	sec	</sec	
	4,000	1,500			
Flight Dynamics					
a) Monitor Vehicle Position	200	50	sec	0. sec	
b) Abort Plan	570	270	90 min	235 sec	
c) Reentry Maneuver or Rendezvous (incl. Agena Control)	6,000	6,000	sec	0. 5 sec	Continuous during reentry
d) Orbit determination (incl. ephemeris)	600	300	45 min	260 sec	Continuous during reentry
e) Contingency extrapolation	1,000	500			
	8,370	7,120			

Table 4.3.4.2-5 (Contd)

	Adds per/sec	Mult per/sec	Basic Cycle Time	Max Run	Remarks
Operations Direction					
a) Summary Status Reports	neg	---	Variable	</sec	
b) Status of test objectives	neg	---	Variable	</sec	
c) Emergency Plan Requests	500	500	erratic	sec/min	
d) Special Status Report Requests	neg	---	Variable	</sec	
e) Contingency extrapolations	1,000	500			
	1,500	1,000			
Display					
Display Format & Refresh	2,000	2,000	0.1 sec to 3 min	</sec	
Special Display Generation	2,000	2,000	Variable	</sec	
	4,000	4,000			
I/0 & Communications					
a) External comm. lines	9,600	2,400	msec	0.2 sec	
b) Intercomputer	neg	neg	msec	neg	
Recovery Control					
a) Recovery Force Status	500	500	1 sec	</sec	
b) Contingency Plans	500	500	Variable		
	1,000	1,000			

4.3.5 Recommended Computer Complex Equipment

4.3.5.1 Recommendations

The computers suitable for the IMCC ground data processing task divide nicely into three classes according to the fractional loading of the computer. The first class includes the Univac 1107, the Philco 211 and the IBM 7090. The second class consists of the IBM 7094 alone. The third class comprises the Philco 212 and the CDC 3600. The computer complement required for each class is shown in Table 4.3.5.1-1.

Table 4.3.5.1-1

COMPUTER COMPLEMENT

Operational Mission Support 4 - UNIVAC 1107s, Philco 211s, IBM 7090s Backup 1 - UNIVAC 1107, Philco 211, IBM 7090 (contains roll-back data)	Operational Mission Support 2 - IBM 7094s Backup 1 - IBM 7094 (contains rollback data)	Operational Mission Support 1 - Philco 212 or CDC 3600 Backup 1 - Philco 212 or CDC 3600 (contains rollback data plus parts of essential program)
Simulated Mission Support 4 - UNIVAC 1107s, Philco 211s, IBM 7090s No simulation backup computer recommend-ed.	Simulated Mission Support 2 - IBM 7094s No simulation backup computer recommend-ed.	Simulated Mission Support 1 - Philco 212 or CDC 3600 Backup 1 - Philco 212 or CDC 3600 (contains rollback data plus part of essential program)

The relative advantages and disadvantages of the extreme approaches are given below in Table 4.3.5.1-2. The IBM 7094 is not discussed in the table, as its features lie between the two extremes.

Table 4.3.5.1-2

ADVANTAGES AND DISADVANTAGES
OF TWO COMPUTER APPROACHES

Factors	Computers Per Mission Control Center: 4—1107 (or Equivalent) Plus 1 Spare	1—Philco 212 (or Equivalent) Plus 1 Spare
Growth	Smaller quantum when adding equipment	Additional equipment requirement remote
Flexibility	Equally flexible	
Communication		
External	Equivalent	
Inter-Computer		Better, less inter-computer communication required
Programming		
Initial Checkout	Better, can be done more easily in sections in parallel on several machines	
Revisions and Maintenance	Better, can be done more easily in sections in parallel on several machines	
Executive Program	Roughly Equivalent	
Costs		
Basic Computer	Greater cost	
Interconnecting hardware	Greater Cost	

The advantages and disadvantages of the two formulations of a computer complex configuration for the IMCC are summarized in Table 4.3.5.1-2. Each configuration has features which would recommend it as a choice for this particular application. Other factors which must be considered, however, before a final choice of a computer system configuration can be made are system reliability, delivery dates, and relative cost, for example.

The successful IMCC computer contractor should use the preliminary evaluation in this report as a starting point in the selection of the appropriate computer complex configuration. Further discussion follows.

4.3.5.2 Computer Configuration Criteria

a. It is possible to perform the data processing task of the IMCC with almost any size computer (see Table 4.3.4.2-4). At one extreme, the entire IMCC data processing task can be performed by a single currently available computer. At the other extreme, the computers to be used can be smaller and smaller until, in the limit, one reaches machines all of whose capability is taken up with the necessary communication among computers, leaving no computing capability.

In determining the optimum size computer for the IMCC Data Processing System, many aspects of data processing system design must be considered. The most important of these aspects, not necessarily in order of importance, are: Growth capability, flexibility, communication, programming, proportional degradation, and cost. Each of these aspects is considered in detail below:

b. Growth. The present requirements on the IMCC are that it shall be able to handle Apollo and Gemini missions, and that one operational mission and one simulated mission shall be handled simultaneously. The Data Processing System that has been proposed to perform this task utilizes a particular Display System designed to result in a minimum load on the computers.

In the future, the data processing load will change. It certainly will change as new types of missions are added. Years from now, for example, the IMCC probably will be called upon to operate in support of a manned flight to Venus or Mars. Even without looking so far into the future, one can predict that the IMCC will probably be required to support manned earth satellites employed for scientific purposes.

The IMCC Data Processing System must also have the capability to cope with changing data processing loads that may result from unforeseen circumstances. For example, if the use of a storage tube TV display system should prove unacceptable or encounter technical difficulties, it should be possible to expand the IMCC data processing capabilities to drive a Display System that might require an order of magnitude greater number of outputs from the computers for displays.

It would be foolish to provide at this time adequate data processing capability for all space systems that the IMCC may be called on to support ten years from now, or for all additional IMCC data processing loads that may possibly result from changes in direction of the space effort, or from unforeseeable scientific or equipment requirements that may be placed upon the IMCC. On the other hand, it is extremely important that growth capability be included in the IMCC data processing system design so that should any of these eventualities occur, it will be possible to cope with them in a reasonable manner by the addition of a reasonable amount of equipment. It is possible to add additional computers, memory stores, controls, displays and communication paths to any of the data processing systems utilizing computers that have been discussed.

The important question is whether it is better to start with one large computer performing the data processing task or whether it is better to start with a number of smaller computers. So far as growth capability is concerned, the smaller computers have an advantage in that the "quantum jump" required for an increase in capability is smaller; that is, if ten computers of a particular size are required to perform the current IMCC functions - then, if the data processing load is increased by 10%, it is only necessary to increase the data processing capability by a like amount. On the other hand, if one large computer is fully occupied with the current IMCC data processing job, then an increase of 10% in the data processing requirements might necessitate the addition of another large computer (assuming that only one size computer is employed) thereby doubling the amount of data processing system that must be supplied.

If this argument is used in support of the data processing complex consisting of a number of smaller computers, then this argument must be pursued to its logical conclusion. Let us say that still another 10% in computing capability must now be added to the data processing center. In the multiple computer system, another one or two machines must be added. In the data processing system that, at this time, employs two machines, it is not necessary to add any additional equipment.

So far as this aspect of growth capability is considered, the important point is that both systems consisting of large machines and systems consisting of a greater number of smaller machines can be increased in capability through the addition of further machines, but that the "quantum jump" for the large machines is greater and is required less often. Systems utilizing either large or small machines are capable of growth as the system requirements increase. The cost of growth and the ease of growth are considered separately in succeeding sections.

c. Flexibility. The IMCC will be called upon to support a variety of missions. At the present time, the planned missions are Apollo and Gemini. It is likely that one month the IMCC may be supporting a Gemini mission, a month later be supporting another Gemini mission with different objectives, or be supporting an Apollo mission. In the future, the variety of missions to be supported may be greater and the changeover time between missions less. Furthermore, in an emergency resulting from the failure of equipment in the GOSS or in the spacecraft, it may be necessary to rapidly alter the functions of the ground data processing system. Within the past few years, computer system design has included a growing capability for this kind of system flexibility.

Data processing systems introduced within the last few years – the Univac 1107, CDC 1604, CDC 3600, IBM 7090-7094, RW 400, B5000 and Philco 2000 – have all included flexibility of machine interconnection and operation as part of their designs. The most flexible of these systems are the B5000 and RW 400, both of which utilize central exchanges for rapid changes in configuration of computers, memories, and input-output devices for adaptation to the solution of problems of different sizes.

All of the systems that have been considered for the IMCC Data Processing System can provide the necessary flexibility to adapt to varying mission requirements.

d. Communication. In the design of the IMCC Data Processing System, three kinds of communication must be considered. These are: communication with the external world in the form of remote sites or GSFC, communication with displays and controls in the IMCC, and communication among data processing equipments within the Data Processing System.

The problems of communication with the external world, whether remote sites or within the IMCC, are much the same whether a single large computer or many smaller computers are employed. The problems of inter-computer communication, however, are far less severe – in fact, almost nonexistent when the single large computer is used. This is an argument in favor of the use of a single large computer.

All of the computers, that have been considered for use in the IMCC, have included adequate provisions for communication with other devices. The adequacy of these provisions and the amount of extra equipment that must be provided for such communication varies from machine to machine.

There are two intercomputer communication problems that result from the utilization of a larger number of small machines. These are (1) that more machine-to-machine communication is necessary and (2) that more communication paths must be provided. If there are N computers and each of these must be able to talk directly to any of the others, then $N(N - 1)/2$ communication links must be provided. For five computers, for example, ten links would have to be provided. Alternatively, if a single multiple link were to be shared by a number of computers, the computers would have to take turns using this link and there would be problems of data capacity of the link and priority, to be considered. These points are discussed at length in another section.

e. Programming. A single large machine or several smaller machines each have some programming advantages in the IMCC Data Processing System.

If a number of smaller machines are employed, the executive routine must coordinate the operations of all these machines. On the other hand, if a single large machine is used, the executive routine must schedule the operations of that machine in such a manner that all functions are performed as often as necessary; this can require sophisticated programming.

Both large and small computers have disadvantages that a medium size computer does not. A large computer (3600) is only used efficiently if considerably extra effort is applied during programming. A small computer (160A) does not lend itself to a problem-oriented compiler, may have a limited word size (bits/word), and in general, is harder to program.

This difficulty does not occur in routine operations, for scheduling of computer functions can be worked out beforehand. The difficulty arises when an operator request for a long running-time program is made. Now, it becomes necessary to provide for interrupting this program at frequent intervals to keep up with routine operations.

Using a number of small machines, it is possible that one program or routine may be too large for one of these machines, and may require transfer of a large amount of data between two machines, necessitating the employment of a higher speed or higher capacity data transfer device than would ordinarily be needed, or may require the close intertwining of instructions and control signals among two or more machines. Although this is true in general, in the specific match of computers and computational tasks chosen for this computer complex, this problem has been avoided. If a single large machine is employed, problems of dividing the computing load in a convenient fashion do not occur.

So far as ease of program check-out is concerned, the single large machine and the plurality of small machines are about the same, so long as no program is so large that it must be shared by two or more machines. For individual programs that are not too large for a single machine, checkout is more efficient on a smaller machine since less equipment is tied up in checking this program. If a single program is too large to fit on one of the smaller machines, check-out is simpler on a larger machine. In checking a complete set of programs, there is no clear cut advantage to one system or the other.

In so far as actual programming is concerned, use of either big or small machines introduces about the same amount of difficulty. If a large machine is used, some additional bookkeeping is required to avoid double occupancy of memory cells. If multiple machines are used, this problem becomes less critical but still exists if more than one program is in that smaller machine at any time. Given adequate memory capacity and this, at present, appears to be the situation, the bookkeeping problem in memory space assignment during programming can be solved in the large machine by block assignment of memory to particular programs.

As new missions are added or as mission objectives are modified, it will be necessary to change parts of the overall data processing program. Where several small machines are used, it may be possible to accomplish this by changing only the program in one of the small machines. If a single large machine is employed, change of part of the program may cause a greater perturbation in the already existing program. This unfavorable situation, however, can be avoided by block assignment of memory spaces to particular programs so that the apparent disadvantage of the large machine in this aspect is not necessarily important.

f. Proportional Degradation One important design feature of the IMCC Data Processing System is that, in case of equipment failures, the system should not suffer degradation in excess of the proportion of the equipment that has failed. We may talk about proportional degradation at this time in general terms, but to get a quantitative or even qualitative solution to the problem of evaluating the relative merits of large and small computers in the data processing system, it is necessary to perform a probability analysis of the stochastic waiting line problem in which the parameters are the number of machines in the system, the mean-time-to-failure, the number of maintenance crews, and the effect on system operation of failure of different numbers of these machines.

One general conclusion can be drawn, however. It is that no matter how many digital computers are employed in the IMCC Data Processing System, overall system reliability can be increased if any machine may be substituted for any other. As an example, consider the case where four machines are required to perform the functions corresponding to a single mission. One of the requirements is that the IMCC Data Processing System shall be capable of simultaneously supporting an operational mission and a simulated mission. For this purpose, a total of eight computers has been specified, in one case. If a ninth computer is employed as a spare, it may be used either with the operational mission or with the simulated mission. In the event of one computer failure, the spare computer is used to replace that computer. If a second computer now fails, it is possible that the operational mission cannot be supported at full effectiveness. If the first computer to fail was in the operational system the spare has already become part of the operational system. If a second computer in the operational system now fails, no computer is available to be substituted for it so the operational mission must continue with only three of the four required computers.

If the organization of the nine computers is mechanized in a different fashion, so that any of the nine computers may be used either with the operational mission or the simulated mission, failure of as many as five computers is possible without any degradation of the data processing for the operational mission. In this situation, after two computers have failed, it may be necessary to rob the simulated mission of computers to keep the operational mission functioning at peak effectiveness. This seems to be a very worthwhile plan.

There may well be a requirement to keep the Data Processing Systems for the operational mission and for the simulated mission electrically separate to obviate any possibility of an error in programming the simulated mission data processing from disturbing processing of the operational mission. This can be achieved at low cost while retaining the capability of using any computer with either mission by having a manually controlled plug board switching center or equivalent device, which is used only when switching a computer from the operational system to the simulation system, or vice versa. Then, a failure in the operational system can be picked up immediately by the spare computer without any manual or human intervention and, following this, an operator can manually bring in another computer to substitute for the one that has failed.

To discuss proportional degradation meaningfully, it is necessary to consider particular numbers of computers, how these computers are used, the failure statistics of these machines, the interconnections of these machines, and the division of loads among them. In this section, only a few qualitative observations can be made. To do this, let us consider two situations which are typical of the Gemini and Apollo missions.

If the Philco 212 or CDC 3600 system is employed, the entire data processing task of the operational mission can be handled by a single computer operating at about 40 percent capacity. However, if only one computer is used, difficult scheduling problems occur when some non-routine programs, such as an operator request, are called for. This programming difficulty can be avoided by processing these special requests in a second computer. This second computer also acts as the "spare" to pick up the normal program if the main computer should fail. With this arrangement, one of the two computers associated with the operational mission is about 30% loaded, and the other about 10% loaded in normal operation. The simulated mission data processing center is similarly equipped. Thus, a total of four Philco 212's or CDC 3600's are used.

If one Philco 212 has failed or is down for preventive maintenance, the operational mission is always equipped with two computers and the simulated mission with one. This means that, when a special operator request must be processed in the simulated mission, it may be necessary to operate in non-real time.

If two of the four computers are down because of maintenance or failure, the simulated mission goes off the aif - although, by more sophisticated programming, and if one were willing to combine the operational and simulated mission processing, it would be possible to maintain both missions.

If three of the four computers are down, the operational mission continues with one computer 40% loaded. In this circumstance, response to operator requests for special programs may be delayed slightly. In this circumstance, also, it is possible, with difficulty, to perform both missions in one computer.

On the other hand, if the IMCC Data Processing System consists of nine Univac 1107 computers or equivalents, four normally associated with each mission, and one spare, then no degradation at all occurs when one of the nine computers has failed, but simulated mission data processing degrades when a second computer fails. In this system, if one is willing to accept greater degradation in the simulated mission, one can continue the operational mission without any degradation whatsoever until six of the nine computers have failed. Of course, if one does this, the simulated mission is entirely off the air by the time three computers have failed.

Irrespective of the total number of computers employed, it is necessary to have some duplication of data storage so that, in the event of failure of any one machine, another machine may have access to the stored data to pick up the computing load.

g. Note on Cost. Calculations of the direct cost of using two larger machines per mission are less than the direct cost of using four smaller machines per mission. These direct costs include only the hardware necessary for each machine. The additional costs of interconnecting machines are not included. The additional costs of interconnecting machines are greater for the smaller machines because of the larger number of interconnections that must be provided.

The reason that the direct costs for the larger machines are smaller is principally that these machines represent a later era of computer design, using faster circuitry and more sophisticated system design. The larger machines thus are able to perform a larger number of operations per dollar of machine operating cost.

SECTION 5
DISPLAY/CONTROL SYSTEM

5.1 OBJECTIVES AND TECHNIQUES

5.1.1 General

The Display/Control System provides the interface between mission control personnel and the systems which handle the flow of information between the IMCC, the GOSS elements, and the spacecraft.

The display portion of the system includes all equipment and facilities necessary for selection and presentation of information. The control portion of the system provides the means by which the IMCC initiates actions or responses.

Information display required for mission control personnel in the Mission Operations Control Room (MOCR) may be divided into two categories: (1) the information they must individually have to perform their assigned monitoring and decision functions, and (2) the information they collectively need to observe the effects of their action on the entire system or mission. The former type of information will generally be presented to the personnel at their consoles or operating positions; the latter type will be presented on large group displays.

Information display to the MOCR support staffs will generally be of a more detailed nature and will consist of historical data, reference data, real-time or near real-time telemetry and spacecraft position information.

The control portion of the system will include all devices which facilitate initiation of system control and corrective actions by MOCR personnel. These may be formatted by the Data Processing System or performed by personnel and are then transmitted via the GOSS Communication System for use or relay by the GOSS remote sites or elements.

The primary objective of the Display/Control System is to maximize the decision-making and resultant corrective control capabilities of the mission control personnel. This requires that information be presented to the appropriate personnel in a manner such that little or no interpretation is required so that most of their time is expended in evaluation and decision-making. Other design objectives of the Display/Control System are enumerated as follows:

a. Presentation of Information. The required information, as determined by information flow, must be analyzed to (1) simplify the presentation of information through processing so that needless tasks need not be performed (e.g., conversion of data or mathematical calculations), and (2) arrive at display characteristics which not only do not require interpretation but indicate or cue the next set of operator actions.

b. Flexibility. The Display/Control System must be capable of accommodating mission or vehicle modifications which affect the information to be presented, methods of presentation or display characteristics, and number of personnel positions. The implementation of such changes should require little time and cost.

c. Standardization and Modular Design. Both standardization of consoles and modular design of console elements are related to the design objective of flexibility. Console structures should be standardized as much as possible, provided standardization does not interfere with function. As a goal, not more than two types of consoles should exist.

d. Expandability. Modular design in itself allows expansion of the console. Sufficient space should be provided on the modules themselves and on the consoles for incorporation of additional functions.

5.1.2 Display/Control Techniques

5.1.2.1 Display Techniques

This section describes display techniques which will be applicable to the Integrated Mission Control Center. All techniques which meet the following criteria are included:

a. Compatible with automatic data processing and data entry
b. Adaptable to changing mission goals
c. Satisfy human factors requirements
d. Can be instrumented using display hardware which will be available during the IMCC implementation time period (1963).

The discussion of techniques in this section is on the system design level. An extensive discussion, listing of parameters, and identification by manufacturer of available display hardware is contained in Appendix 5A. Aspects of the IMCC displays, subject to change as mission control personnel and mission goals change, are:

a. Data formats
b. Data content
c. Symbology and coding
d. Display control and utilization
e. Distribution of personnel
f. Distribution of displays.

Aspects of the IMCC displays which are not likely to change are:

a. Human factors
b. Physical laws
c. Physical size of IMCC building, once constructed
d. Physical size of major display components, once installed
e. Overall display objectives, as previously described.

Therefore, the techniques to be described are those which hold some promise of meeting objectives and fixed display aspects, yet provide the flexibility necessary to allow easy and inexpensive adaptation to requirements generated by evolution of the changeable display aspects. To clarify the evaluation of the various display techniques, a discussion of some of the variable display aspects is given for two-dimensional displays. The topic of three-dimensional displays is covered separately.

a. Data Formats. Display formats must be chosen to reduce operator reaction time in understanding displayed data. One of man's greatest advantages over machines is his ability to correlate and clarify data which interrelate in a manner too complex or obscure for machine interpretation. The display system will be used to compare different activities, coordinate different functions, and display conflicts. The information must be made available in formats which most clearly show these interactions, relationships, and conflicts. Figure 5.1.2.1-1 shows some of the wide variety of formats used in displaying information.

   Many kinds of information can be presented effectively in alphanumeric text form. The capability of using such a format is a basic requirement in the IMCC. However, certain types of data cannot be presented effectively in alphanumeric form. Examples are: flight paths, maps, meteorological patterns, areas of coverage, and trend indications as shown by graphs. These are best represented by line drawings. Actual pictures of devices, situations, or people make effective displays which cannot be well presented with either line drawings or alphanumerics. Line drawings and actual pictures will also be valuable at the IMCC. Some data, such as the current value of a quantity being measured (time, fuel remaining, temperature, etc.) often have a display format dictated by the availability of inexpensive display hardware in common use (clock, meter, gauge, etc.). Other data having only two values (on or off, completed or not completed, correct or incorrect) can be displayed using even simpler devices such as lights or electro-mechanical flags. The design goal for the IMCC will be to provide as much format flexibility as is consistent with reasonable cost and equipment complexity.

b. Data Content. The amount of data simultaneously on display at the IMCC will be large, but all the data in the system cannot be displayed at one time. Factors which prevent simultaneous display of all data are human factors such as visual acuity and physical considerations such as display resolution, registration, and brightness. Since all information cannot be simultaneously displayed, provision must be made for easy accessing of "out-of-sight" data to bring it into view.

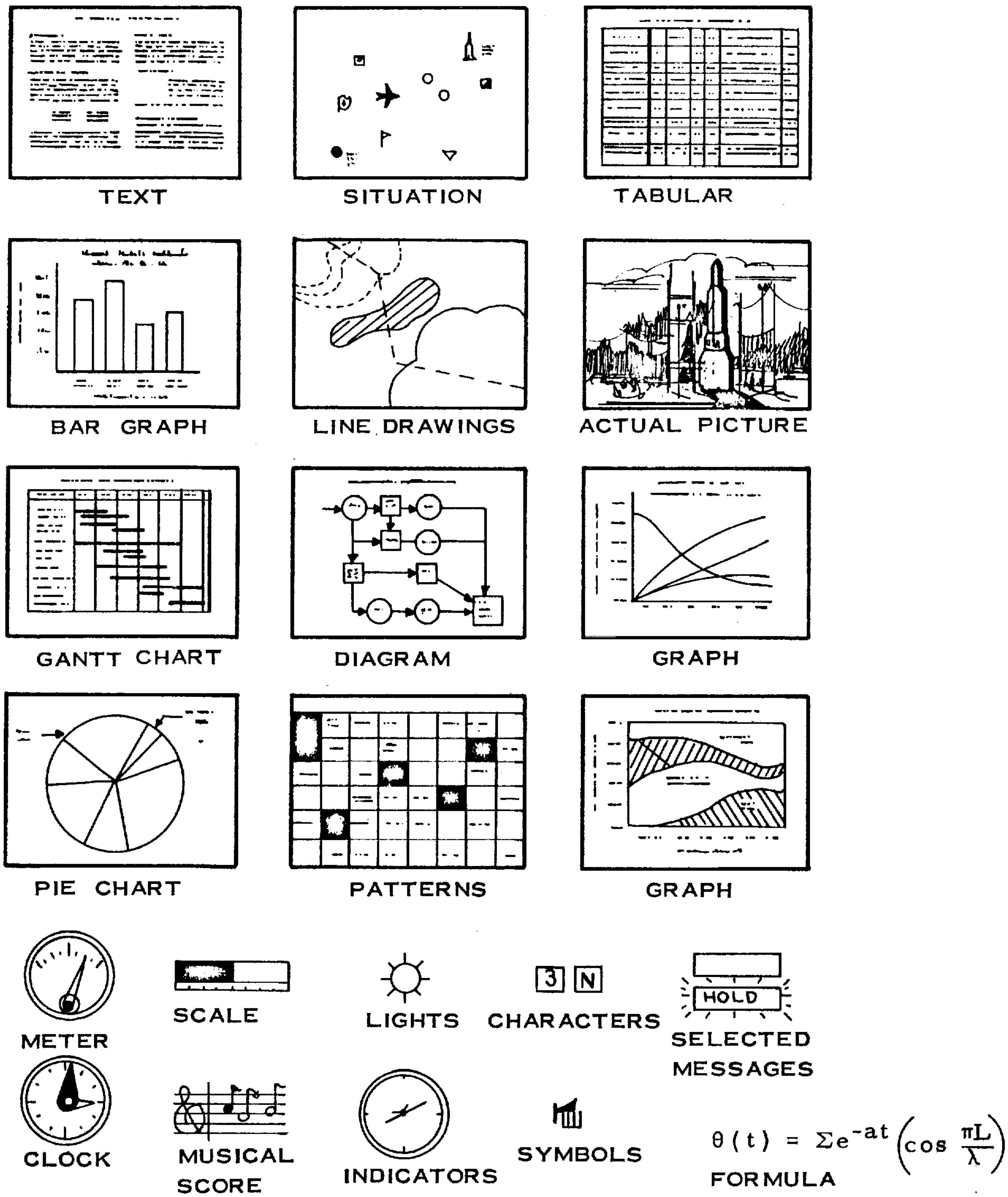


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Figure 5.1.2.1-1 Typical Display Formats

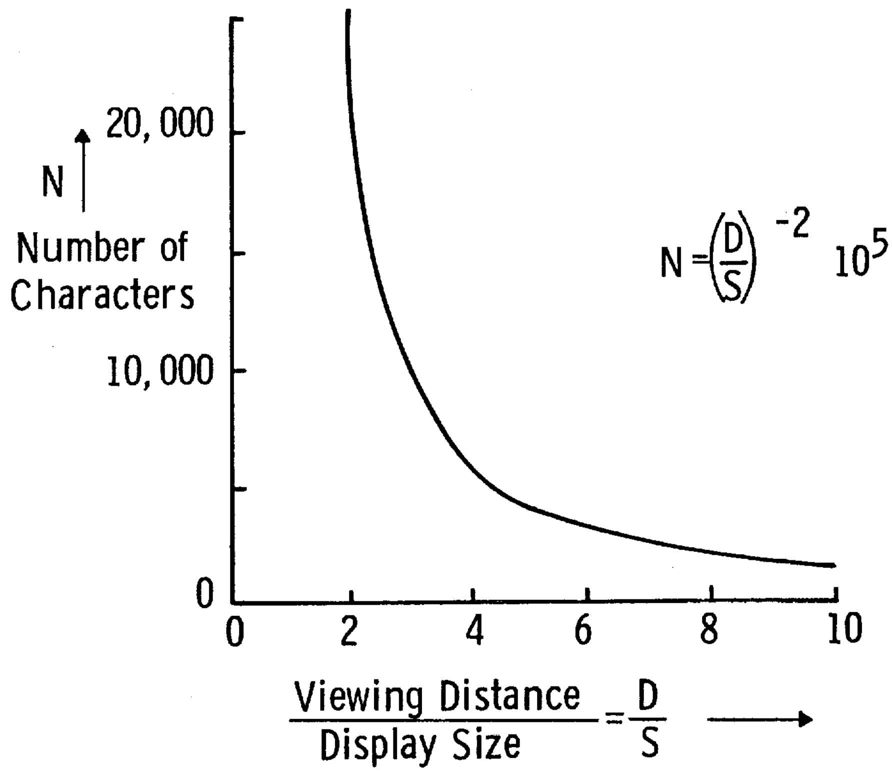
The limitation on display data content imposed by human factors has resulted in a set of criteria for typical viewers:

The human eye, in normal light, can discriminate lines that are about 1.5 minutes of arc apart, using parallel black lines separated by intervals equal to the line width. This gives a resolving power of 2300 line pairs per radian. The solid angle about an individual and the resolution of the eye limit the amount of information that can be displayed simultaneously to that person. Of course, the complete solid angle around a person cannot be used for displays. Aircraft cockpits represent an example of the use of a large solid angle for displays and controls, but even there much of the angle is lost to the seat and other area behind the pilot.

Since the amount of information to be displayed depends primarily on the solid angle subtended and the resolution of the eye, the distance of the display from the user is not significant as long as the ratio of display size to viewing distance does not change. A quantitative description of the maximum amount for alphanumeric data which can be read from a display is given by the curve of Figure 5.1.2.1-2. The figure shows the number of simultaneously displayed characters which are readable at various viewing-distance-to-total-display-size ratios. If a square display is assumed, the display size variable "S" may be considered to be the height of the display. The height of each character on the display "H" is such that the character subtends 10 minutes of arc at viewing distance "D" (H=0.003D). It is also assumed that the vertical distance between rows of characters in 0.5H, horizontal spacing between characters is 0.1H, and character width is 0.65H. The curve applies for conditions of adequate brightness and contrast and a viewing distance greater than 13 inches. No provision is allowed for margins at the edge of the display. The values from the curve or formula of Figure 5.1.2.1-2 demand a viewer with at least 20/30 vision and may be used both for individual displays and group displays.

Another limitation on the amount of information displayed is the response time required and the rate at which information can be assimilated by the viewer. If a person must respond to certain information very rapidly, he does not have time to comprehend a great amount of detail. Thus, a small amount of highly summarized information should be presented when rapid decisions are necessary. With enough time, very complex and detailed displays can be studied and understood. The choice of amount of data displayed must be consistent with the IMCC mission.

c. Symbology and Coding. Although written language is now one of man's most indispensable tools of communication, it is not necessarily the simplest or most efficient means of representing thoughts. It is a compromise which limits the number of



Conditions:

1. Square Display
2. Character slot as shown
3. Character height, H, subtends 10 minutes of arc at viewing distance, D, (H=.003 D)
4. Increased viewing distance at display edges is neglected
5. Adequate brightness and contrast exist
6. Viewing distance, D, is greater than 13 inches
7. No margin allowed at display edge

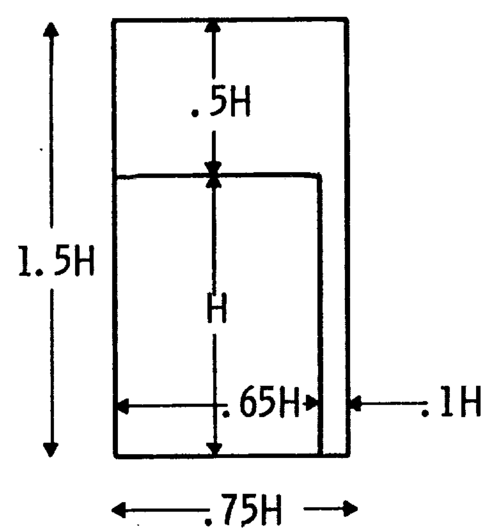


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Figure 5.1.2.1-2 Number of Characters That May Be Displayed vs. Ratio of Viewing Distance to Display Size symbols required. It is still necessary to supplement the alphanumeric and punctuation symbols of our language with special symbology to facilitate visual communication with displays. It is more effective and requires less space to represent a physical object such as an aircraft by its pictorial outline than the combination of letters "aircraft". The meaning of such pictorial symbols is easily learned and reremembered. Use of special symbols to represent nonphysical abstract quantities such as "validity" is possible, but the number of such symbols which can be learned and reliably remembered is limited.

Other means of coding information in visual form are listed in Table 5.1.2.1-1. The approximate maximum number of permissable coding levels for independent recognition is also estimated.* This number will vary with the specific situation and with the number of combinations of coding modes in simultaneous use.

Table 5.1.2.1-1: Coding Data for Display

Method of Coding	Coding Levels (Maximum)
(1) Color	10
(2) Size	3
(3) Shape	
Alphanumeric and punctuation	50
Abstract	16
Pictorial or suggestive	1000
(4) Position	
In one dimension	vertical or horizontal: 5; depth: 3
In two dimensions	9
In three dimensions	12
(5) Orientation	8
(6) Line width (boldness)	3
(7) Number of items (quantity)	7
(8) Flicker or blink rate	4
(9) Intensity (brightness or gray scale)	4
(10) Line length	5
(11) Line type (dotted, dashed, etc.)	4
(12) Distortion (focus, shape, etc.)	2
(13) Motion	10

*Estimates are a consolidation of opinions by Dr. S. Smith of MITRE and by specialists in the contractor's organization.

It is known that NASA is attempting to standardize the shapes of several often-used symbols. The displays chosen for the IMCC should be capable of presenting data using the recommended symbols. At the IMCC, a combination of the best of the listed coding methods will be selected for use with the formats best suited to the mission. Again, the display hardware must possess inherent adaptability to new coding techniques.

d. Group Displays vs. Console Displays. In the IMCC, displays can be classified as one of two types: physically large displays intended for simultaneous viewing by a group or physically small displays mounted on consoles for viewing by one or two people. The selection and use of each type will be based on the following advantages of each:

1. Advantages of Group Displays.

(a) Where information requirements of a number of people are similar or identical, a group display can reduce the total amount of equipment.

(b) A working group can coordinate efforts and communicate more effectively since it is assured that each is seeing exactly the same display.

(c) The group display provides a feeling of continued participation for temporarily idle console operators, avoiding a feeling of isolation.

(d) Certain users are better able to transfer and apply experience gained using group displays.

(e) Support personnel and non-participating observers can anticipate the concerns and requirements of personnel responsible for decisions.

(f) Briefings and group instruction are more effective using group displays.

(g) Redundancy contributed by many people viewing the same display provides operational reliability.

2. Advantages of Console Displays.

(a) Information may be displayed which exactly fits the task requirements of the console operator rather than a composite display not optimized for everyone.

(b) Displays can be changed at will to gain access to different information without interrupting others.

(c) The man-machine link is more effective when entering data, pointing, annotating, or individually planning.

(d) More diverse equipment is available to mechanize physically small displays.

(e) Redundancy of displays of critical functions provides greater reliability.

(f) The deployment of personnel and equipment has more flexibility than for group displays.

(g) Displaying identical data simultaneously on all console displays approaches the capability of group displays for coordination.

e. Display Equipment and Its Effect on Computer Programming. A comprehensive survey of equipment which gives promise of being available during the construction of the IMCC (1963) is detailed in Appendix 5A. If the display techniques and equipment described in Section 5. 3 as recommended for the IMCC are adopted, they will be of two types:

1. Dynamic situation displays capable of showing line drawings and randomly positioned symbols
2. Selectable fixed displays.

Most of the display data processing will be concerned with driving equipment of the first type which may be a mix of:

1. Digital to television converters driving console and large-screen television displays
2. Servo-controlled scribing mechanisms
3. Servo-controlled individual symbol projectors or pointers
4. X - Y plotters.

An important consideration is that all these diverse devices can be driven by a computer using a single data format. The computer sends out a succession of two-dimensional coordinates. Along with each coordinate is a descriptor character. If symbol generation is done in the computer, the descriptor will control whether or not a line is made visible while the line is traced to the next coordinate. According to the mechanism chosen, this can blank a cathode-ray beam, lift a scribing mechanism, close a shutter, etc. The only real difference will be in the operating speed of the driven device. Since it seems most practical to transfer data out of the computer asynchronously, speed considerations will not effect the format of data stored in the computer. Using a single format allows any display to be sent to any device without format conversion. For example, a computer-generated display primarily intended for the digital-to-TV conversion system could be put on a Kollsman scribing projector with no additional data processing.

If symbol generation is done outside the computer by separate small symbol generators, the descriptor character accompanying each coordinate-pair would also be used to identify the symbol to be produced. Again, the actual mechanization of the symbol generation (electronic, mechanical mask positioning, etc.) need not affect the format. The only effect is a change in response time.

To minimize the amount of display data processing and storage, the single format approach for all dynamic situation displays is recommended. To allow a quantitative evaluation of the amount of processing, to allow the capability of driving any recommended dynamic display, and to allow simple incorporation of similar devices which may become available in the future, the following standard data word format might be used:

1. Coordinate portion: 11 bits X and 11 bits Y
2. Descriptor portion: 6 bits (one out of 64 symbol types)
3. Control portion: 2 bits (four types of word possible)

This gives a 30-bit word format, compatible with many computers suitable for the display data processing task.

The selection of fixed displays by the computer will be a smaller part of the display data processing load. These selections include turning on lights or alarms, selecting a film slide, setting a meter or digital readout, etc. Since these devices each have unique requirements, it will be impractical to think of displaying a given type of data on a choice of different equipment types. Thus, for these latter displays, the single format described for dynamic displays is not applicable.

f. Control Techniques. Displays and controls will be provided at the JMCC with one major objective in mind: to improve the decision-making by those responsible for the success of the mission. This will be accomplished in three ways. First, the required information flow must be analyzed and mechanized so as to simplify operations and eliminate needless tasks. Second, the displays must improve the availability of data necessary to make rapid, accurate decisions. Third, when the data has been made available, it must be presented in a form which aids understanding by the decision-makers. Thus, there are two categories of control: selection of what is displayed and control of the mission based upon decisions made by viewing the displays.

g. Display Selection and Utilization. When the information required by an individual to perform his functions exceeds the capacity of his displays, means must be provided to change the information displayed. Display access time is an important characteristic of display systems. This is defined as the time lapse between a user's request for new information and the display of that information. The access time is a function of both human factors and the physical equipment. Human factors can be the largest contributor to long display access times if the amount of out-of-view data is large. In such a case, the data is stored away according to coded addresses which cannot all be remembered by the user. Thus, an intermediate step is required in which the user consults an index or an information service function to learn the required code. Once the descriptors for the desired data are known, varying degrees of automation can be provided to speed the changing of the displays. Examples of ways to gain access to new displays are:

1. Searching. The display may be sequentially changed to present portions of the stored data to the viewer. The user allows changes to continue until the desired information comes into view, at which time the operator stops the the sequence of changes. This is quick and simple to mechanize if the total number of possible changes is small.

   A variation of this which can be even faster is to provide several displays of which only one or two can be comprehended simultaneously by the user. To gain access to more information, the user merely shifts his head and eyes from one display to the other. This is the most rapid and convenient method where fast access is required. The technique is less convenient but still valuable if the user must physically move over to another display. Access by shifting the head and eyes from one display to another will be one of the most used methods of accessing new information on group displays.

2. Separate Button for Each Category Keyboard. Depressing the proper button calls for the proper display. A variation of this approach, which gives added flexibility, is to provide blank buttons which are identified by changeable descriptor sets. When a descriptor set is in place, each button has a fixed meaning represented by its own code plus the descriptor set code. Changing the descriptor set and code gives a new set of meanings to all the buttons. Descriptor sets may be implemented as roll charts, projected film frames, or physically changeable plastic or metal overlays having slots through which the buttons protrude.

3. Numeric Encoding. Where the number of categories is large, setting up a code number on multiple buttons greatly reduces the number of buttons required. For example, when decimal numbers are used to indicate display categories, one out of 1000 displays can be selected by three activations of a decimal keyboard. A different mechanization of the same accessing method is the telephone dial.

4. Language. Displays can be requested by using an alpha-numeric keyboard to enter a limited syntax language or logical statements which can be machine interpreted. If the display is to be changed manually, verbal instructions represent the same accessing method.

5. Pointing. Where data is already on display, but the viewer wishes to change the level of detail to some other predetermined level, the data to be affected can be designated by pointing to it. To specify manual changes, pointing with the finger or a rod is adequate. To point out such changes to a machine, several ingeneous devices have been built including:

   (a) Light Pencil or Light Gun. A photosensitive detector which picks up the flash of data being regenerated on a cathode ray tube. The timing of the pulse from the light pencil is correlated with the timing of refreshing the data to identify the data selected.

   (b) Conducting Stylus. The display is coated with a transparent electrical conductor across which a two-dimensional voltage gradient is established. Touching the display with a conducting stylus changes potentials to indicate position coordinates of the displayed data.

   (c) Pointer Mechanically Linked to Position Encoder. A stylus whose position is measured by a mechanical linkage to two shaft encoders can be placed directly over the desired data or a small "joy stick," "track ball," or other two-dimensional positioning device may drive both a position encoder and a displayed pointing mark for remotely selecting data.

   (d) Television Visual Amplification. The picture is determined by where the camera is pointed and by choice of optical magnification.

A recommendation for a Display/Control System utilizing a flexible combination of some of these techniques is described in Section 5. 3.

5. 1. 2. 2 Control Techniques

The equipment available to implement the control objectives requirements described in Section 5. 1. 1 will be a combination of the following techniques:

a. Separate Button, Switch or Valve for each Decision. Manually actuating the proper button or handle initiates the corresponding control function. Where the number of categories is small, this is the simplest control technique. Adaptability to new system requirements requires two changeable properties: the labels on the devices (usually buttons in an electronic system) and the control function performed by each. These two must change together. Examples of degree of flexibility include:

   1. Adaptability Only by Reworking or Rebuilding. If adaptability is not planned, labels will be firmly fixed (engraved, painted, etc.) and control functions will be firmly attached (hard wiring, fixed linkages, etc.). Changes in meaning and function require much time and rework. In the IMCC, this technique should be reserved for a minimum number of relatively permanent functions such as control of primary power, room lights, and selection among a few large pieces of equipment.

   2. Planned Manual Adaptability. If the buttons are labeled with adaptability in mind (holders for changeable captions, roll charts, etc.) and meanings are adaptable (plugboards, coded in conjunction with separate code source, etc.) changes can be made between missions neatly and easily. Such approaches will be stressed in the IMCC design.

   3. Planned Automated Adaptability. If the meaning of a button is specified by a flexible computer-driven display (cathode ray tube, printer, etc.) and if the button merely signals a computer to start a control sequence which is a function of a changeable program, adaptation may be highly automated. Often the higher cost of automated adaptability requires that manual adaptability be chosen.

b. Numeric Encoding. Where the number of control functions is large, setting in a sequence or parallel grouping of code numbers greatly reduces the number of buttons or switches required. As in the previous example, numeric encoders can be planned for no adaptability, manual adaptability or automated adaptability.

c. Language. Control can be exercised using an alpha-numeric keyboard to enter a limited syntax language statement for machine interpretation. The keyboard may be attached to a tape punch, a card punch, or any other computer input device. Special message/composing machinery which contains internally stored format aids, selective error correction, and display on a cathode ray tube is now available. Such devices will be used infrequently at the IMCC because of their high cost.

   Ordinary language will be the primary tool used when men rather than machines are being controlled. Direct or telephoned verbal instructions and teletyped or otherwise digitized commands will be very much a part of the IMCC system.

d. Pointing. Any of the pointing techniques described under "Display Selection and Utilization" may be applied to mission control. In addition, any of the other display control techniques may be used to change the display for a viewer and so direct his efforts.

Because of the multitude of available buttons, knobs, levers, switches and other simple devices available to implement controls and because of the obvious application of familiar communication devices for control, a detailed listing is not a part of this report. Appendix 5A does include a large number of display devices which may form parts of the IMCC control system.

5.2 SYSTEM FUNCTIONAL REQUIREMENTS

5.2.1 Display Requirements

5.2.1.1 Introduction

Analyses of MOCR manning concepts and display information requirements were presented in WDL Technical Reports E114 and E114-2. Action displays were defined as the working tools for displaying information. Examples are displays of the status of vehicle systems, astronauts' condition, powered flight and orbital parameters, trajectories and other information deemed essential to the decisions and actions required of mission controllers. In contrast to summary information on mission progress, action information requires more detailed considerations of mission functional requirements and their consequent actions and decisions and are allocated to individual mission controllers according to an appropriate division and assignment of responsibility. Summary information on mission progress is presented on large displays for use by all personnel in the MOCR.

5.2.1.2 Areas of Responsibility in the MOCR

The functional areas of responsibility, identified in earlier reports, were:

a. Flight dynamics monitoring
b. Spacecraft systems monitoring
c. Life support systems and biomedical monitoring
d. Voice communication.

In addition to this, there are two other kinds of information which need not be allocated to individual mission controllers but may be included in a large wall-map type of display. These are:

a. GOSS remote site and communication network status
b. Summary information on overall mission progress.

While this list may not encompass all activities in the MOCR, it is sufficiently complete to include and illustrate the tasks required of mission controllers and to identify the information they need to perform these tasks. It should be emphasized, however, that these areas are by no means mutually exclusive; they may overlap; and their information requirements almost certainly will, since identical information will be used for different but interacting areas of responsibility.

In the reports mentioned above, these separate areas of responsibility were considered in some detail to identify Mission Controller tasks and detailed operations, and to relate these to information requirements. In the present discussion, this analysis will be extended to include consideration of possible display devices, using Flight Dynamics monitoring as an illustrative example. The use of Flight Dynamics as an example is particularly appropriate for two reasons, (1) Flight Dynamics monitoring appears to be one of the most critical functional operations required in the MOCR and (2) Flight Dynamics monitoring requires such a wide variety of displays that most important display types for the other areas are included.

5.2.1.3 Flight Dynamics Display Information

In the reports previously mentioned, information requirements for Flight Dynamics were identified for all phases of a Gemini Rendezvous Mission. It was envisioned that the information could be displayed using four basic display types:

a. Event indicators for displaying the occurrence of normal or emergency events during the mission (ordinarily in some sequence)

b. Time indicators for showing times remaining and actual or estimated times of event occurrence

c. Dynamic situation displays for displaying spacecraft coordinates and derived quantities such as velocities, accelerations and attitude. (This category may encompass devices ranging from computer hard copy and numerical indicators to coordinate plots.)

d. Group displays to provide an overview of mission status and cues as to future events and upcoming action/decision responsibilities.

Table 5.2.1.3-1

FLIGHT DYNAMICS DISPLAY INFORMATION

Information Items For Display	Information Sources	Information Utility	Remarks and Possible Display Devices
I. Event Indicators			Mission Phase: Launch, Powered Flight and Orbit Insertion.
A. Titan/Gemini			
1. First Stage Firing	Telemetry (TM) from Launch Complex via land line or microwave	Indicates Launch Complex has initiated Gemini launch	Coded indicator light located to show place in the sequence of pre-launch and launch events
2. Lift-off (LO)	TM from Launch Complex	Booster off the pad and clamps released; start of direct IMCC mission control	Coded indicator light arranged in sequence; this event coincides with start of Gemini Elapsed Time (GET)
3. First Stage Engine Cut-off (FSECO)	TM from booster via Cape Canaveral	Powered flight progress; FSECO time compared with pre-planned nominal limits (probably by computer)	Sequentially located coded indicator light; if FSECO occurs too soon or too late or fails to occur, abort may be necessary
4. Second Stage Firing	Same	Indicates powered flight progress; preceding remarks apply	Coded indicator light showing correct sequence; preceding remarks apply
5. First Stage Separation	Same (if included in TM)	Powered flight progress; Titan staging complete; preceding remarks apply	Coded indicator light sequentially arranged; preceding remarks apply
6. Second Stage Engine Cut-off (SSECO)	Same	Same	Sequentially arranged coded indicator light; preceding remarks apply

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Sources	Information Utility	Remarks and Possible Display Devices
7. Gemini Separation	TM and/or voice from Gemini	Indicates separation achieved; events 3—8 are timed and compared with pre-planned nominal limits. Together with other TM on booster performance and initial tracking, they are evaluated by computer to give go or no-go indication for orbital insertion	Coded indicator light arranged in sequence; Items 3—8 are time critical; failure to occur or incorrect timing may result in extreme insertion parameters or failure to achieve orbit. In either case, abort may be necessary or rendezvous attempt may not be feasible.
8. Guidance Status; Go or No-Go	GE/Burroughs computation and guidance complex, based on booster TM and initial tracking	Go: Titan responding correctly to guidance commands. No-Go: Not responding correctly to guidance commands	Coded indicator lights; Go, Green; No-Go, Red. Not a sequential event and should be spatially separated from them for emphasis
9. Orbit; Booster Go or No-Go	Computer recommendation based on insertion parameters	Go: Insertion parameters acceptable. No-Go: Insertion parameters unacceptable	Coded indicator lights separated from sequential event indicators: Go, green; No-Go, red
10. Orbit Capability	Computer estimate of number of orbits possible, derived from insertion parameters	Information: If orbit capability is less than planned, rendezvous attempt may not be feasible	Numerical Indicator Light: Items 9—11 are related and should be located together, but separated from sequential event indicators for emphasis

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Sources	Information Utility	Remarks and Possible Display Devices
B. Atlas/Agena			
1. Firing Signal	TM from Launch Complex via land line or microwave	Indicates Launch Complex has initiated Agena launch	Coded indicator light arranged to show sequence
2. Lift-off	Same	Booster off the pad and clamps released; switch-over to direct IMCC control of mission; start of Agena Elapsed Time (AET)	Coded indicator light arranged in correct event sequence; this event also marks start of MET, if Agena launched first
3. Booster Engine Cut-off (BECO)	TM from booster via Cape	Atlas staging complete; BECO time is compared with acceptable limits known prior to launch (probably by computer	Coded indicator light arranged in sequence
4. Sustainer Engine Cut-off (SECO)	Same	Powered Flight Progress above remarks apply	Same
5. Agena Separation	TM from Agena via Cape or down-range sites	Indicates Agena separation achieved; preceding remarks apply	Same (Firings of explosive bolts may be indicated in sequence)
6. Agena Engine Start	Same	Indicates that Agena main engine has started; Agena should separate from booster; above remarks apply	Same type of indicator; Items 3–7 are critical; failure to occur or incorrect timing may result in extreme insertion parameters or failure to achieve orbit. Abort may be necessary or rendezvous attempt not feasible

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Sources	Information Utility	Remarks and Possible Display Devices
7. Guidance Status; Go or No-Go	Booster and Agena TM and initial tracking	Go: Atlas and/or Agena (after separation) responding to guidance commands or flight plan. No-Go: Atlas and/or Agena not responding correctly to guidance commands or flight plans	Coded indicator lights: Go, green; No-Go, red. Not a sequential event
8. Orbit; Go or No-Go	Computer recommendation based on insertion parameters which are derived from booster and Agena performance TM and initial tracking	Go: Insertion parameters acceptable. No-Go: Insertion parameters not acceptable. Abort may be required	Coded indicator lights. Go, green; No-Go, red
9. Orbit Capability	Computer estimate of the number of orbits possible, derived from insertion parameters	Information: If orbit capability is insufficient, rendezvous attempt may not be feasible	Digital read-out. Items 8–10 are related and should be grouped together, but separated from sequential event indicators for emphasis
C. Emergency Events			
1. Abort Request; Gemini	Abort request signal generated by Range Safety, mission controllers in IMCC, by Gemini crew, by Launch Complex personnel or by computer	Indicates that abort is believed necessary. This event will be displayed at most mission controllers' positions, at Launch Complex, in the spacecraft and at Range Safety Office	Large coded red indicator light located for emphasis.

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Sources	Information Utility	Remarks and Possible Display Devices
2. Abort Command; Gemini	TM from the spacecraft; initiation of abort sequence	Abort initiated	Large coded amber indicator light
3. Ejection Initiate (Separate indicators for each seat)	TM from the spacecraft	Indicates that the ejection mechanisms have fired	One coded indicator light for each astronaut. These three emergency events (1—3) are related, and their indicators should be grouped, but separated from other indicators for emphasis
II. Event Time Indicators			
Discussion: It is assumed that sequencing, timing and initiation of launch and powered flight events such as ignition and cut-off of stages (see items A3—A8 and B3—B7, above), are automated, and that time indicators for these events are neither necessary nor desirable. Failure to occur or incorrect timing and sequencing will automatically activate an associated red warning light/switch for any event provided with a manual back-up initiation mode. If manual initiation does not subsequently occur within established time limits or there is no provision for manual back-up, the Abort Recommend and Orbit No-Go indicator lamps will be activated immediately after positive verification of a malfunction.			
A. Launch, Powered Flight and Insertion Event Times			Times below not specifically related to this phase are listed here because the timing starts prior to or at launch.
1. Universal System Time, probably GMT	Established time standards	A universal time to which all mission events are referred; displayed at IMCC, all remote sites and in Gemini	Digital read-outs hours, minutes and seconds. Standard 24-hour clocks may be usable for some purposes.

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Sources	Information Utility	Remarks and Possible Display Devices
2. Launch Countdown; First Vehicle	LCC launch countdown for first vehicle launch	Hours, minutes and seconds remaining to first vehicle launch	Digital read-out showing time remaining directly in hours, minutes and seconds. Desirable to provide labeled "Hold Count" lamp, in addition to stopping counter when the count is interrupted. Estimated duration of hold may be displayed, also, if available.
3. Launch Time Limits; Second Vehicle	Tentatively established by pre-mission planning, up-dated after first vehicle launch	Second vehicle launch time limits acceptable for achieving rendezvous	Digital read-out showing the upper and lower time limits within which second vehicle launch must occur.
4. Launch Countdown; Second Vehicle	LCC launch countdown for second vehicle launch	See item 2	See item 2, including remarks; may use same indicator if countdowns not concurrent.
5. Mission Elapsed Time (MET)	Accurate time sources	Hours, minutes and seconds elapsed since first vehicle liftoff	Digital read-out showing hours, minutes and seconds directly
6. Gemini Elapsed Time	Same	Same, substituting "since Gemini LO"	Same
7. Agena Elapsed Time	Same	Same, substituting "since Agena LO"	Same

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Sources	Information Utility	Remarks and Possible Display Devices
8. Retrofire Times a. Estimated Retrofire Time b. Time Remaining (countdown)	Estimated prior to launch, updated as required	Pre-launch estimate of retrofire time, updated as data become available and also displayed as time remaining	Digital read-outs started at launch and updated
Discussion: As long as they are readable, the time indicators above (except for 8a and 8b) need not be located in the flight dynamics area. They may be included with the large group displays.			
9. Impact Time	Computer and/or manual estimates of impact time, based on retrofire parameters and expected reentry and glide path length	Inform appropriate recovery forces	Specific display may not be required, computer hard copy print out. Digital read-out for countdown to impact may be applicable
III Graphic Relation Displays (Spacecraft Location Displays)			These display orbital parameters, location coordinates and related quantities, such as velocity, acceleration and range rate for the Gemini and the Agena
A. Launch, Powered Flight and Insertion 1. Gamma: the angle between booster velocity vector and local horizontal	Computed value based on vehicle sensors and TM, possibly early tracking by GE/Burroughs complex	Compare with known acceptable limits (computer and/or manual comparison)	Computer-driven digital readout in degrees and tenths or degrees and minutes

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Sources	Information Utility	Remarks and Possible Display Devices
2. Velocity vs. Altitude	Computed values using TM from vehicle sensors and radar data	Same	Computer generated plot—may be direct-view plot board or projection. Also may utilize TV display and call-up on demand. May be part of group display during launch
3. Altitude vs. Range	Same	Same	Same
4. Velocity Ratio	Computed value indicating the ratio between present and desired velocity; approaches value 1.0 at insertion	Same; see item 5	Computer-driven digital readout; see item 5
5. Gamma vs. Velocity Ratio	Computed values (see items 1 and 4)	The most critical information for orbital insertion. If either gamma or velocity ratio are outside certain limits at insertion (and they are interdependent), the orbit may not be acceptable for achieving rendezvous or for crew safety, or both	A plot (computer-driven TV or projection) showing gamma as a function of velocity ratio. When V_R reaches a critical value (say 0.90), both scales should expand to show detail, and acceptable limits should be clearly marked on the expanded surface. Numerical values of gamma and V_R should be included in display

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Source	Information Utility	Remarks and Possible Display Devices
6. Longitudinal Acceleration	Telemetered indication of acceleration along the powered flight path	Indicative of booster performance and powered flight progress	Digital readout and plot vs time remaining to SECO (Agena) and as function of time remaining to SSECO (Gemini). See item 7
7. Inertial Velocity	Computer estimate based upon TM from booster (integral of item 6)	Same	Same; inertial velocity and longitudinal acceleration may be displayed as separate curves on the same surface if desired, since they are both shown as a function of SECO for the Agena and SSECO for Gemini
8. Predicted Insertion Altitude	GE/Burroughs guidance computer using TM from booster and tracking data	Indicative of guidance system performance and acceptability of present trajectory to satisfy altitude criterion. Both Gemini and Agena	Computer-driven digital readout and plot (computer-driven TV or projection)
9. Perpendicular Velocity component	Same—(Velocity component to left or right of desired flight plane)	Same—(Extreme deviation may require abort or cancellation of rendezvous attempt. Both Gemini and Agena)	Same: Items 8 and 9 may be displayed together as a function of elapsed time; possibly needed only on demand
10. Yaw Deviation	Computed deviation to left or right of desired flight plane, based on information in item 9 and early radar tracking	Same	Computer-driven TV or projection plot of right-left deviation vs. downrange distance. This and item 3 may be displayed together

Table 5.2.1.3-1 (Contd)

Information Items For Display	Information Source	Information Utility	Remarks and Possible Display Devices
11. Predicted Impact and Recovery Locations	Powered flight trajectory and abort mode employed (seat ejection or para-glider landing); computer estimate may not be accurate	Impact and Recovery point estimates for on the pad and powered flight aborts	Chart or plot of estimated impact points super-imposed on map covering possible landing areas; may be supplemented by numerical indicators for latitude and longitude. Initial computer estimates may be less accurate than down range radar tracking or visual sightings not yet available to computer

Discussion and Recommendations: When two variables are to be displayed as a function of the same third parameter (e. g. , Elapsed Time), present both on the same display. Provide display request buttons for variables not needed continuously during powered flight and insertion, so that information may be presented as needed on computer-driven TV displays and projection screens. Since many of the parameters above need be displayed only during powered flight and insertion, these displays can be used to present other information during later phases of the mission

Table 5.2.1.3-1 represents a translation of these information requirements into possible display devices for the launch and powered flight phase of a Gemini Rendezvous Mission. Column 1 contains information for event indicators, event time indicators, and graphic relation displays; column 2 indicates information sources; column 3 illustrates how the information is used; and column 4 contains amplifying remarks and mentions possible display devices. Under each of the three display categories, the information requirements follow an assumed mission chronology.

5.2.2 Command and Control Requirements

5.2.2.1 Introduction

In Gemini and Apollo missions, the spacecraft is relatively autonomous compared to Mercury, for at times ground-based information is not sufficient for controlling the spacecraft. (During the terminal phases of Gemini rendezvous, for example.) Nevertheless, the IMCC retains overall responsibility for mission control and for coordinating the operations of all system elements. This responsibility includes selection of mission objectives and mission rules, and the perogative of changing them if conditions warrant, as well as actual command of the Agena vehicle during most phases of Gemini rendezvous missions. In effect, then, the GOSS remote sites, the Gemini spacecraft, and the Agena vehicle are the agents by which the IMCC conducts operations to fulfill certain objectives; namely, the rendezvous in orbit of a manned spacecraft and an unmanned target vehicle.*

The Gemini crew is given authority to initiate Gemini and Agena actions only insofar as these are consistent with objectives and rules established prior to launch and updated by the IMCC as the mission progresses. The IMCC will determine what maneuvers and other actions are necessary to achieve rendezvous, and relay these to the Gemini crew via the appropriate GOSS command sites.

In addition, the IMCC will control the Agena directly, except in the terminal phases of rendezvous, when control of the Agena will be delegated to the crew.

*The choice of a Gemini rendezvous mission for illustrating control concepts has no particular import, but is based primarily on the following considerations: (1) more information is available for Gemini than for Apollo operations and (2) overall mission control concepts for Apollo should not be drastically different than for Gemini, at least as far as the IMCC is concerned.

To achieve effective mission control, the following kinds of activities will be required:

a. Control of data sources and relay points, (the GOSS remote sites). This aspect of control if mostly arranged in advance, in terms of the data available from the various sites and their functions in the network. In addition, there will be real-time commands (RTC's) issued during the mission to request additional data and changes in format, and to designate which sites are to serve as relay points for transmitting commands to the Gemini and the Agena. These remote sites are the information sources (radar) and relay points for spacecraft data (telemetry and voice) that the IMCC utilizes in controlling the mission.

b. Control of the mission, by commands to Agena and Gemini. In essence, the mission is pre-planned, but nominal times for initiating maneuvers and performing other actions are updated as the mission progresses, utilizing tracking data from the remote sites, and telemetry and voice reports relayed from the vehicles by the remote sites. The IMCC will determine what actions are necessary, when they should occur, and by whom they shall be initiated. This will include the following aspects:

   1. Selection of appropriate maneuvers in terms of velocity increments, thrust parameters, etc., for both vehicles

   2. Selection of appropriate remote sites for relaying commands and information to Gemini and Agena

   3. Selection of appropriate commands, including RTC's and stored program commands (SPC's) for both vehicles: these commands will activate thrusters in the Agena, but will be used primarily for updating on-board data for Gemini; Gemini thrust parameters may be also entered by ground command, but it is assumed that the crew will initiate them

   4. Selection of voice-transmitted information for Gemini; the IMCC will determine whether maneuver parameters and other data shall be entered into on-board programmers by direct ground command or by the crew, and insure that the information is transmitted and verified accordingly: The voice link is expected to be the normal command mode for Gemini.

5.2.2.2 Control Concept

a. Information Flow and Mission Control. To achieve mission control, the IMCC must accept information from many sources, evaluate this information, make decisions and transmit data back to appropriate system elements. IMCC outputs will include commands and recommendations as well as integrated data not otherwise available at the remote sites or in the spacecraft. This concept is briefly illustrated in Figure 5.2.2.2-1, for the rendezvous mission.

b. Control Requirements. These may be summarized by the following items:

1. Evaluating input information, including:
   (a) Radar data
   (b) Telemetry from Gemini and Agena
   (c) Voice from Gemini
   (d) Remote site status information
   (e) Weather data
   (f) Recovery force status
2. Selecting commands, including:
   (a) Real-time commands to remote sites to:
      (1) Request information
      (2) Select sites for relay to spacecraft
      (3) Request changes in data format, etc.
   (b) Real-time and stored-program commands for Agena and Gemini to:
      (1) Store data in on-board programmers
      (2) Initiate actions (primarily Agena)
   (c) Voice commands to Gemini, including,
      (1) Information for crew entry into on-board programmers
      (2) Action initiation requests
      (3) Requests for data
3. Transmitting and verifying commands
   (a) From IMCC to remote sites
   (b) From remote sites to Agena and Gemini
4. Monitoring results of commands. When a series or sequence of maneuvers or other operations are employed, it is desirable for the IMCC to evaluate actually attained results before subsequent events are initiated. This may not always be possible (for example, during the terminal phases of rendezvous, assumed to be under direct crew control), in which case, IMCC personnel must rely on computer predictions generated by extrapolating from past data and the maneuver parameters employed. In

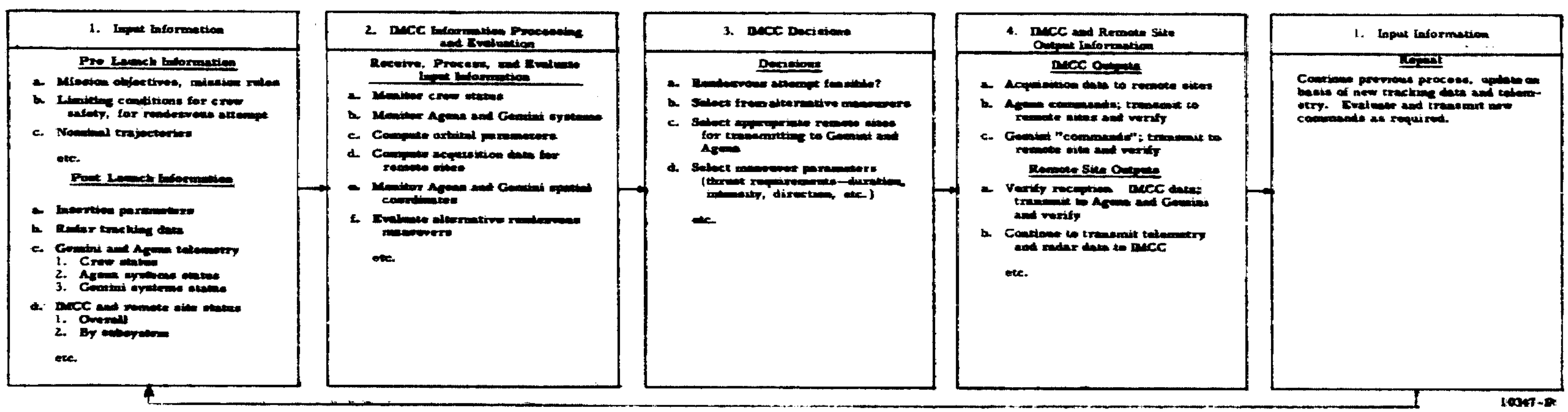


Figure 5. 2. 2. 2-1 Illustrative Information Flow for IMCC Control

any event, the IMCC must monitor and evaluate results of maneuvers, whether these are actually attained values based on new tracking data and telemetry, or computer predictions. This process of continuous monitoring and evaluation will enable the IMCC to anticipate future requirements and potentially dangerous situations, to prepare new commands or to intervene if necessary.

Figure 5.2.2.2-1 and the four items above are a bare outline of a control concept which will be expanded, revised and detailed in later analyses.

5.3 DISPLAY/CONTROL SYSTEM RECOMMENDATIONS

5.3.1 General

It is the purpose of this section to describe a Display/Control System configuration which appears at this time to best satisfy the Integrated Mission Control Center (IMCC) during Gemini and Apollo missions. Some of the objectives and requirements considered in making the following recommendations have been discussed in paragraphs 5.1 and 5.2 Investigations of various detailed display methods shall continue. The choice of displays is based upon implementing system information flow using display techniques which are currently available or in an advanced state of development. The recommended display devices meet the described requirements (provide flexibility for easy change of data format, data content, symbology and coding, and display utilization).

5.3.2 System Concept

The recommended system makes data available to IMCC decision-makers in a form which allows clear understanding so that rapid, correct evaluations can be made. The choice of terminal equipment conforms to human factors requirements, laws of physics, and reliability requirements. It will fit into the proposed IMCC building. Briefly, this display concept is based upon television monitors, large screen projection television, dynamic large screen projection displays (such as Kollsman or National Cash Register), servo-controlled light spot projectors, status lights, digital readouts, clocks, meters, plotboards, strip chart recorders and alphanumeric printers. Since the amount of data in the IMCC system is so large, it cannot all be comprehended or even displayed simultaneously. Thus, it is important to provide mechanisms for easily changing the content of the displays so that data currently necessary to make rapid, accurate decisions is always available to mission control personnel. Flexibility in the recommended display concept is achieved by: (1) the use of data processing equipment to provide system programmability, and (2) the use of high precision television techniques as the primary display medium. The utilization of programmable display driving equipment and non-fixed format display devices will permit the system to adjust to changing mission requirements with a minimum of disruptions. It will further result in a standardized and straight-forward design of display positions.

An extensive closed circuit television system is recommended as the primary IMCC display medium. Such a system provides a common display device capable of:

a. Being driven from a number of sources with different output characteristics.
b. Presenting displays in varied formats, i.e., alphanumeric, graphical and pictorial.
c. Functioning as a group display device (projection TV) as well as an individual console display.
d. Providing a convenient, uncomplicated and inexpensive method of information distribution to widely separated end points.

This last feature (d) permits the system to act both as a display medium as well as a communication medium for the transmission of pictorial information.

Major components of this recommended IMCC display system which is based on high precision television techniques are shown in Figure 5.3.2-1 and include:

a. Computer output to television converters
b. Pictorial video generators
c. Off-line data files
d. Video distribution facilities
e. Television display devices

Components (a), (b), and (c) represent display system inputs. While television techniques are generally familiar as a means of converting a pictorial scene to an electrical signal which can be transmitted over distances and reconstituted as a pictorial display of the original scene, any device which can generate a synthetic video signal can serve as a system input. Computer output to television converters are typical of this type of device. They will accept any computer output which must be converted to graphical or alphanumeric presentations and from this input generate such a synthetic television signal suitable for distribution and display. Components (b) and (e) provide conventional television inputs, i. e., they are used to convert reference information from off-line files or pictorial data which are manually generated in the support areas to television signals. Included in this category are inputs which may be received from other GOSS elements, such as launch pictures from the launch control center, or spacecraft-originated video signals relayed via a remote site.

Component (d) includes all facilities which are necessary to select, distribute and transmit video signals generated by components (a), (b) and (c) to the various display devices. Component (e) provides the actual display transducers. It should be emphasized that one of the major advatages of the recommended system lies in the availability of display transducers which can work with a wide variety of input sources (digital computers, slides, documents, etc.). These display transducers will consist of high precision television monitors for direct-view applications and television projection devices for group display.

5.3.2.1 Computer Output to TV Converters

Computer generated displays are entered into the system via computer output to TV converter channels. Appendix 5B provides an operational description of the recording storage tube on which the device is based. Digital information derived from the data processing system may contain line information, alphanumeric/symbol information or combinations of both. Such information is conventionally displayed by means of X-Y plotters or CRT displays, where digital information is converted to X-Y position of a plotting actuator (i. e., stylus, pen, or electron beam). In conventional CRT devices, it is required to regenerate the information at a high rate (30 to 60 times per second) to overcome display flicker. In order to present static reference information such as coordinate

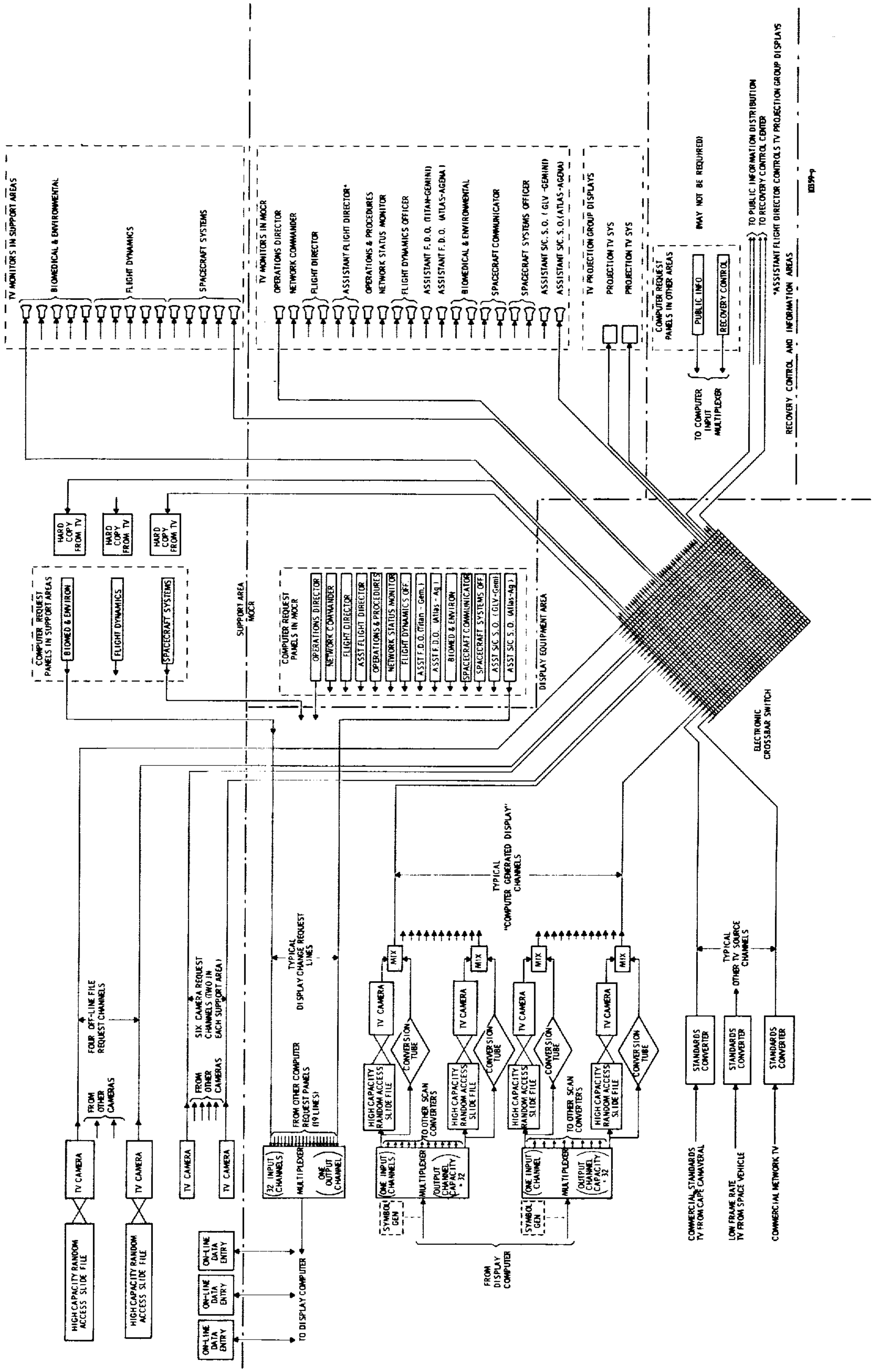


Figure 5.3.2-1 MOCR Television System

backgrounds in conjunction with the dynamic information, it is necessary to store this information in digital form or to use a combination of CRT display with optical projection. Both these features are wasteful of data processing storage and limit the flexibility of the display, since it is necessary to tailor the display transducer to the information content.

In the recommended system, dynamic information represented by digital data processing outputs is also converted to X-Y positions of an electron beam. This electron beam, however, does not generate the visual display. Instead it is used to deposit charge patterns on a dielectric material. These charge patterns are read by a second electron beam which is deflected in the television raster standard and scans the dielectric material. The presence or absence of charge patterns causes this beam to be modulated. This modulation then forms the signal output of the device. The presence, absence or degree of modulation as a function of time within the television raster process results in a standard television signal suitable for distribution to any television display device. The dielectric material which contains the computer generated information has storage capability which will reduce the need for information regeneration from 40 to 60 per second to rates which are between one per 2 minutes to one per 10 minutes, resulting in a substantial reduction of computer output requirements. The high repetition rate of the television raster process, in addition to line interlace, results in a flicker-free display even under high display brightness conditions. The television raster process provides accurate position synchronization of the electron beams for all devices which are part of such a system, i. e. the instantaneous position of the electron beam in any display generator corresponds point-to-point to the position of the electron beam in all other display generators and all display reproducers. This permits the generation of a separate video signal for reference information from two-dimensional storage such as photographic slides and the electronic addition of such a reference signal to the dynamic computer-originated information. The use of appropriate access devices for this reference information permits storage of this static information outside the data processing equipment without sacrificing the advantages of all electronic information distribution and display. Since both computer generated dynamic information and the associated reference information are contained in a composite video signal, such information may be distributed to any display device, regardless of location or assignment, by means of standard television switchings and transmission techniques.

Associated with and part of each converter channel will be a reference generator. The reference generator is a random access aperture card file combined with a high resolution vidicon camera to view the slides contained on each card. Each reference generator shall have a complete repertoire of reference slides so that the computer is free to select any converter for any display during operations. At the time of selection, the computer will generate an address word for access of the proper slide. The reference generator provides background information for computer generated display data and may only be addressed by the computer. The slides may contain coordinate information, maps, and other background material. The output of a vidicon camera which views the slide will be directed to a video montage amplifier. The video outputs of the scan converter tube and of the reference generator will be combined in this video montage amplifier. Basically the device acts as a fast switch, keying out the reference signal whenever there is coincidence with the signal generated by the converter. The signal output of the montage amplifier is a composite of the two signals and may be distributed in the normal fashion.

It is recommended that there be a converter channel assigned to each console located in the Mission Operation Control Rooms and three converter channels to each of the main support areas. As presently envisioned, the converter channels would be allocated as follows:

a.	MOCR Consoles	15
b.	Flight Dynamics Support Area	3
c.	Spacecraft Systems Support Area	3
d.	Life Support and Biomedical Support Area	3

e.	Assigned to Group Displays	2
f.	Assigned to Simulation Center	2
g.	Total each MOCR	28

The provision of a converter channel for each console position assures the availability of a channel for each user during periods of maximum activity.

5.3.2.2 Off-Line Data Files

It is recommended that off-line reference data files be maintained for the purpose of storing mission rules, engineering drawings of vehicle systems, contingency action procedures and recommendations and any other miscellaneous data that might be required for ready access. This file will consist of a random access aperture card file, optically coupled to a high resolution vidicon camera. The files shall have a nominal capacity of 5000 cards each and a reasonably fast access time not to exceed 5 seconds. Four such data files shall be used to support personnel in each MOCR as follows:

a. The Operations and Procedures Officer, for the storage of rules and procedural options
b. The Flight Dynamics Support Group, for the storage of reference material pertaining to maneuver planning, etc
c. The Spacecraft Communicator, for the storage of mission schedules, test objectives, and predetermined alternate objectives.
d. Spacecraft Systems Support Group, for the storage of engineering drawings of vehicle systems, system specifications, and "trouble shooting" guides pertaining to both vehicles.

The files would be assigned only to the indicated functional groups and would be accessed directly by these groups. A selection mechanism, such as a pushbutton panel may be used to generate coded request words that direct the file to an information category and then to category subdivisions. The vidicon camera output will be fed to a fixed video distribution channel known to the users.

5.3.2.3 Miscellaneous Camera Sources

Support areas associated with the MOCR console positions will be equipped with high resolution cameras. These cameras will be used to transmit any manually generated charts, plots or analytical data to operating positions in the MOCR. Six camera chains are presently assumed, two in each support area. Outputs of these cameras will be fed to fixed video distribution channels known to the MOCR operators. Additional cameras will be provided to view the main group display presentations in the MOCR. The outputs of these cameras will be available on distribution channels which are accessible to the support areas and to other peripheral operations which require overview of the mission status. These will typically include the recovery control area, the mission briefing and observation area and perhaps certain areas in the office, laboratory and support wing.

5.3.2.4 Video Distribution Facilities

To obtain the utmost advantage from programmable display generators and the general display concept, a distribution facility will be required. The function of this facility is twofold:

a. Distribution of operational display information to the mission operations and support positions and the group display subsystem

b. Distribution of selected displays for non-operational purposes to observers within and outside the IMCC.

The overall distribution system for television display information originated by the sources described under 5.3.2.1, 5,3,2.2 and 5.3.2.3 will utilize standard, established techniques for high quality television facilities. It will be based on crossbar switching matrices. (Duplicate facilities will be required for the two MOCR's). Each information source which has a television type output signal, (i.e., computer output to TV converter channels, cameras and remote inputs) will be connected to an input buss on the matrix. Each information recipient; i.e. console displays, group displays, special monitors and outgoing lines) will be fed from an output buss of the matrix. Any input may be connected to any output by closing an appropriate switch (relay or solid state device) at the point where the selected input buss crosses the output buss of the display device on which the information is to be presented. Special interlocks are provided to prevent the switchings of more than one input to any output. The video distribution matrix may be located at any desired location remote from the selection position. Actuation of the switching facilities is provided by control circuits. Once chosen, an output will remain connected to the given output buss until a new selection is made at which time it will automatically drop out.

In addition to the switching facilities the video distribution facilities will include a number of additional terminal equipment components such as video distribution amplifiers, video patching facilities and quality control monitoring equipment. These components will be located in a television control area.

5.3.2.5 Video Display Selection and Control

It is necessary to integrate the display selection and distribution concepts to describe the operation of the video display system which is shown in Figure 5.3.2-1. Three distinct request and selection actions are envisioned at this time. These are: (1) video display selection, (2) computer request, and (3) off-line file data request.

Video display selection enables each user to request and receive any television display available to the distribution matrix. The user cannot, however, cause the generation of a new display by means of this selection process.

A console-originated control signal will actuate the connection of any of the input busses on the distribution matrix to the output buss for the monitor on which the display is desired. Each console in the MOCR and each operating position or console in the support areas will be equipped with a control mechanism to select any video input for display on its monitors. This capability is recommended to provide full flexibility for display access, regardless of functional responsibility of individual operating positions and to accommodate any changes in display requirements. It will further permit any operating position to observe the displays which are active on any other operating position. If necessary, access to information can be restricted by appropriate procedure or by disconnecting the control circuits to matrix inputs which are to be denied.

Computer request, as distinct from video selection, causes a particular display to be generated by the data processing system and written on a converter channel. As with video selection, it implies a console generated code, but requires that this code be recognized and responded to by the computer. The code must identify the information requestor as well as the information desired. Identification of the request originator is needed if converter channels are not fixed assigned to given display monitors. At present there are two methods under consideration.

Method (1) would provide a system where converter channels are not fixed assigned to display positions. In this system converter channels will be assigned by the computer to any requesting display on an availability basis. The provision of converter channels on a one-per-requestor basis will ensure that a channel is available at any time. Loss of a channel would not require substitution of a spare during the mission but would only increase access time for the users. This method would be in keeping with the concept of proportional system degradation in case of equipment failure which is followed in the data processing system concept. It does however require a more complex method of computer display request actuation, since the computer will have to select an available converter and also ensure that the video output of that converter is routed to the requestor's display. A typical computer request cycle in method (1) would proceed as follows: the requestor would set up a request code (using pushbutton, telephone dial, simple punch card reader or other digital selector device) on a small module at his operating position. This request is transmitted to the computer when he depresses a display release button associated with the video select controls and will clear the display monitor on which he desires the information to appear of any previously active display. The computer will note the request, access the material requested and search for a free converter channel. While routing the digital information to the selected free converter, the computer will also actuate an additional control which causes the switching of the converter channel to the requesting display automatically. Figure 5.3.2.5-1 represents a flow diagram of the request actions. This automatic action may be manually backed up by providing a return code which identifies the selected converter to the requestor. The operator then actuates the indicated channel on his video selection control and receives the display. It is recommended that capability to request information will be assigned to each operating position so that only those displays pertaining to the function of that operating position may be requested. It may be desirable to program this limitation in the display/control data processor, or this could be accomplished by appropriate patch connections prior to the mission that would allow only certain codes to be transmitted by a given console.

The computer request and video display request capabilities, when combined, add great flexibility to the system. Channel failures during long missions, even if several failures occur simultaneously, are not catastrophic since a user may repeat his request and receive it on another channel. If the reduced number of channels causes all channels to be in use, he would have the option of pre-empting one of the less important display channels by procedural priority.

Method (2) which is also under consideration at this time would result in some simplification of the display request procedure. In this system each display format required by a given control position would be written on a separate converter channel and constantly up-dated by the

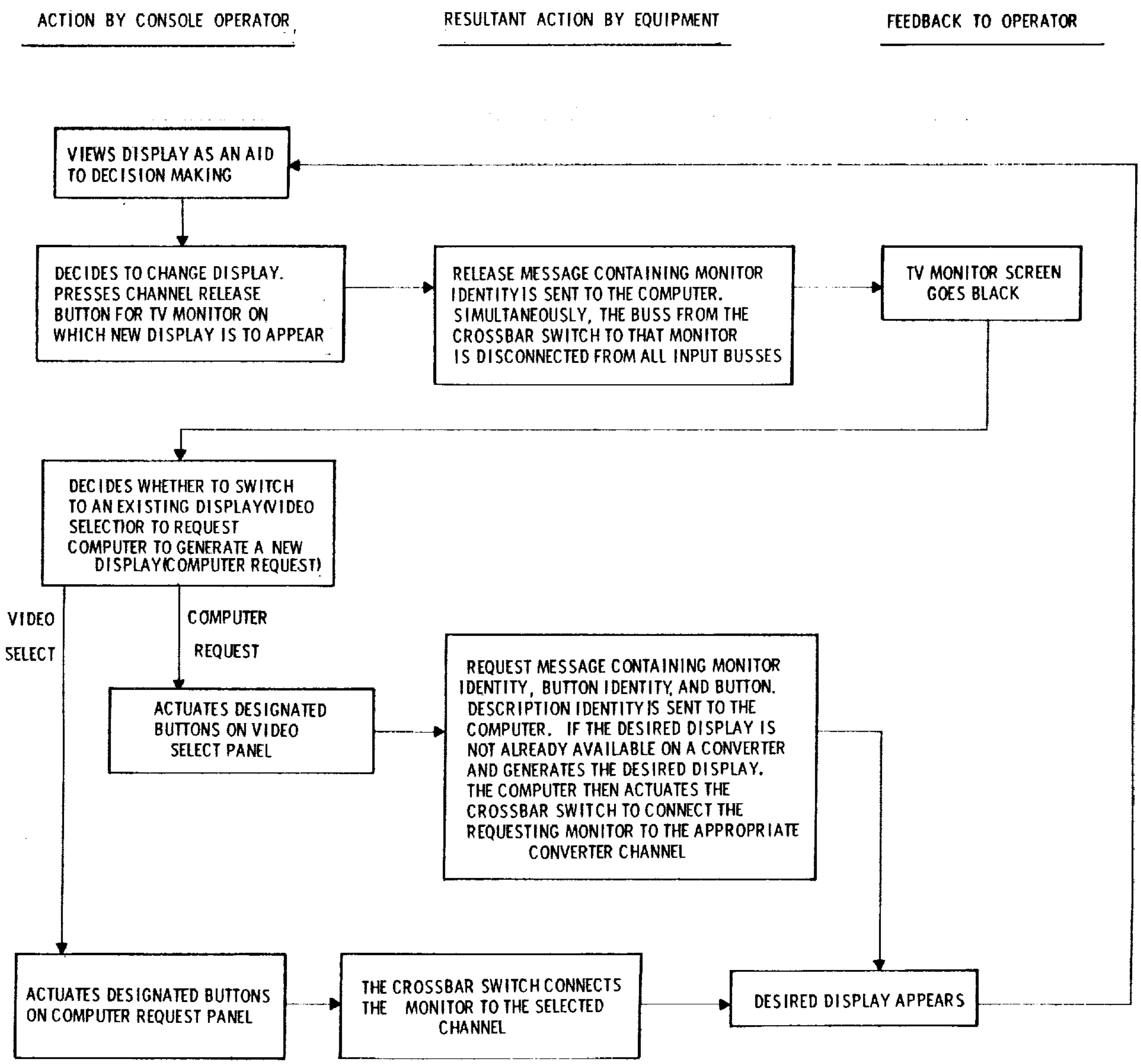


Figure 5.3.2.5-1 TV Display Change Flow Chart

computer in accordance with the regeneration cycle. A number of display channels would be available at each operating position and selection would be made simply by actuation of the video selection controls. Such a system would result in a much simplified selection process. It would be feasible only if the number of fixed display formats required does not exceed the number of converter channels which can be provided without making the system overly complex and expensive. In addition to the fixed assigned display channels a number of request channels as provided in method (1) could be provided to obtain display formats not normally assigned. The selection of such displays and associated computer request action could be delegated to personnel in the support areas. If a non-standard display format is required by a console position in the MOCR the operator could request that such information be accessed and transferred to his display via voice intercommunication with his support area. While method (2) appears attractive and more straightforward from a display selection and control point of view it cannot be recommended at this time. A decision on whether method (2) is preferrable will require a complete analysis of the number and format of displays which are required during Gemini and Apollo missions. Since the difference between the two approaches is primarily one of display control programming and does not involve fundamental differences in display system configuration, this decision will be deferred until a complete analysis of the MOCR and support area display requirements and display formats is completed.

Off line data requests pertain to only four operating positions as described under Section 5. 3. 2. 2. Again a selection device such as a pushbutton panel may be used to generate a code signal. In this case, however, the code word would be routed directly to an address register located in the random access aperture card equipment. A file system associated with a functional position in the MOCR will contain reference material that is pertinent to that position. It is estimated that no single file would contain more than 1000 cards and that an average number might be 250 cards. (Equipment with 5000 card capacity is, however, available.) To facilitate access, these will be divided into category groups, each group consisting of a nominal 10 to 100 cards. The code will first identify a group and then a card in the group. Provision will be made to allow the user complete random access to any card or to address the lead card in any group and then, by depressing a button at intervals, to step through all the cards in the group in sequence. Cards are viewed via television display. A camera "reads" the card and outputs a video signal on a known channel assigned to that display.

5.3.2.6 Television System Characteristics

The television system which has been recommended as the primary means of computer output display as well as multipurpose general display will have special characteristics which are different from normal broadcast or industrial systems. Poor display quality and stability which are sometimes inherent in industrial systems cannot be tolerated. The recommended system will have precision circuits and will probably operate at higher line rates than either industrial or broadcast systems. The operating standards will be dependent on the density and format of the information displayed. Precision television system components are available to make up the majority of the display, distribution and signal origination facilities which are required. System performance specifications which will ensure that the system will meet requirements are contained in Appendix 5C. System requirements and design details will be further developed in future issues of this report.

5.3.2.7 Data Processors

For purposes of continuity in describing the Display and Control System, some of the major functions of the display data processors (in the Display and Control Data Processing Subsystem) which were discussed in Section 4 are presented below.

The data processor will accept inputs from two sources: (1) raw data extracted from the real time data stream by the input/output data processor and (2) processed data from the real-time data processors.

Functionally, the display/control data processors shall perform, but not be limited to, the following tasks:

a. Recognize data by category and sort, process, store, format, and distribute the data to its display end points

b. Perform an analysis of some of the more significant parameters (such as testing a temperature data sample to determine whether it has exceeded some predetermined limits) and automatically alert the appropriate display end point

c. Select certain parameters for special treatment such as trend analysis or tabular displays or combinations of these

d. The processors will keep a historical file in auxiliary memory of all parameters and must be capable of generating a composite display of the total or partial history of any parameter selected by request.

e. The data processors shall be capable of recognizing requests generated by console operators. The computer will recognize the source of the request as well as the material requested. The computer will then select a converter to output its data and cause the converter to be connected to the monitor of the requestor. The computer shall also be required to update or rewrite all displays so generated on a periodic schedule.

f. The data processors shall provide command processing (or shall provide address words to the real time data processors). If the need for previews of the consequences of a command or series of commands is established, then the display processors shall access the necessary inputs from the real time data processors and generate the display.

In the performance of the above tasks the data processors will generate displays on a request basis, assigning displays to channels on an availability basis and regenerate the displays at intervals to be determined by information rates and the storage capabilities of the converter channels.

The data processors shall be required to provide sufficient flexibility to meet the expanding requirements of mission evolution through programming technique rather than equipment replacement.

5.3.3 Console Display/Control Instrumentation

5.3.3.1 General

The previous section described the conversion of digital information to display signals, containing dynamic graphical and alphanumeric information, the generation of other pictorial information and the distribution of such multi-format display data by means of closed circuit television techniques. The primary display end points will be located at the various control, monitoring and operating positions in the Mission Operation Control Rooms. While it is considered that television display devices will satisfy a large portion of the dynamic display requirements, a number of other control and indicating devices will be necessary to complete the instrumentation of MOCR consoles.

In order to preserve flexibility and expandability with changing mission requirements, an attempt should be made to standardize display/control devices on the various consoles as much as possible by providing modules which only differ in the number of devices installed but not in basic appearance, wiring or function. The following basic modules have evolved as a result of initial analysis:

a. CRT-TV Display Module (TVDM)
b. CRT-TV Display Select Module (TVSM)
c. Display Request Module (DRM)
d. Event Sequence Indicator Module (ESIM)
e. Event Time Indicator Module (ETIM)
f. Communication Module (CM)
g. Command Initiation Module (CIM)
h. Status Monitoring Module (SMM)

5.3.3.2 CRT-TV Display Module (TVDM)

The TVDM is the central console display device. It is essentially a precision, high-resolution television monitor. Certain consoles will be equipped with more than one TVDM to permit side-by-side presentation of two parameters or simultaneous presentation of different types of information. The TVDM will be capable of presenting pictorial, dynamic live, as well as alphanumeric or tabulator, displays. Dynamic live and alphanumeric or symbol information may be intermixed in accordance with the display format requirements. Since the TVDM is a general-purpose display television monitor, its design and internal circuitry is totally independent from the display format. Its information or signal input will consist of a single coaxial cable. It follows that all TVDMs may be exactly alike, and any unit may be replaced with a single type of maintenance spare. The TVDM will employ a 17-inch diagonal diameter cathode ray tube for direct viewing. Operating controls will be limited to display brightness and contrast adjustments.

In order to convey an impression of the type of display which may be presented via the TVDM, a simulated display format has been prepared. This format may be considered as typical for the biomedical and environment monitoring console, and is shown in Figure 5.3.3.2-1. (Real display formats will require considerable analysis; the format shown does not imply a recommendation). The example was prepared graphically. The resulting drawing was then placed in front of a high-resolution camera channel, and the resulting display was photographed from the face of the cathode ray tube.

The display provides a combination of alphanumeric data and graphical trend chart, and would (in the real system) have been generated on request by one of the computer output to TV converters which have been discussed in Section 5.3.2.1. The actual numeric measurements and the trend-line constitute dynamic information as generated by the computer, written by the "write" beam and read-out by the "read" electron beam in the converter tube.

The display also contains reference information such as the descriptions of biomedical and suit environment captions, and the coordinate grid and labels on the graph. This information would be contained on a slide in the reference generator which is part of the converter channel. The two resulting signals would then be combined by the video montage amplifier and the resulting composite signal would be transmitted to the biomedical and environment monitoring console where it would

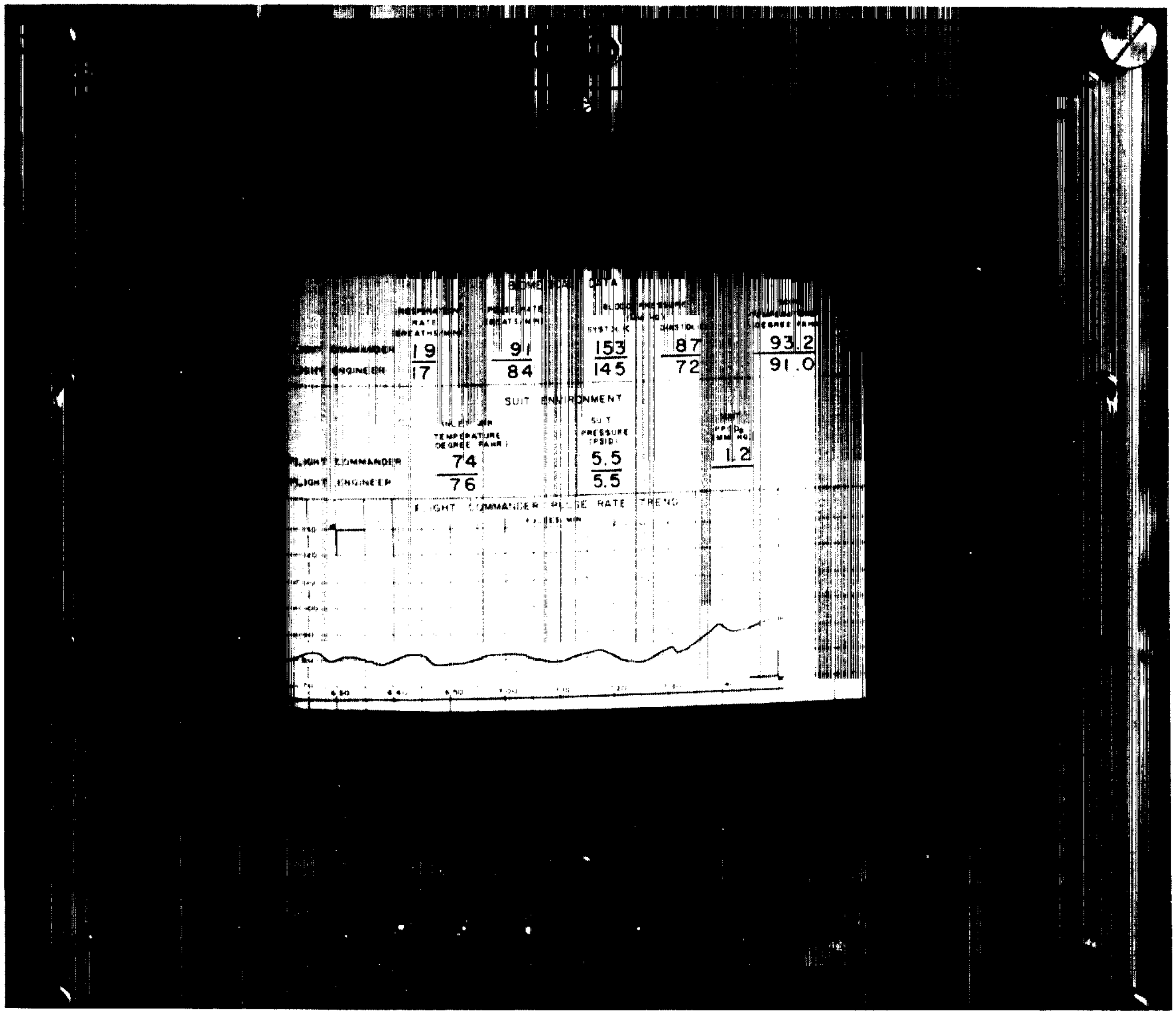


Figure 5.3.3. -1 Biomedical and Environment Monitoring Console Display Format

appear on the TVDM as shown in the figure. It should be noted that the dynamic information content of the display such as the trend-line, the trend-line time markers and the numerical measurements would be updated by the computer at rates which are determined by the receipt and processing of new information and by the display re-generation cycle which will occur between two and five times per minute.

The general display format discussed above is equally applicable to numerical display of the status of vehicle systems function and the graphical presentation of system performance trends. It may similarly be used for display of spacecraft location or graphical relation plots and numerical read-outs at the flight dynamics positions.

The generation and display of diverse formats can be extremely flexible and will be limited not by the display system but by the number of display subroutines which are available in the display/control data processing subsystem.

5.3.3.3 CRT-TV Display Select Module (TVSM)

A Display Select Module (TVSM) will be required for each TVDM. This is a simple device consisting of a row of push buttons which control the manual selection of displays for the TVDM. The TVSM remotely controls the selection of any input buss on the distribution matrix for connection to the output buss to which the associated TVDM is connected. If "n" display sources are available, the TVSMs will contain a row of "n + 1" momentary contact pushbuttons. The selection control is equipped with interlocks which automatically drop-out the last display and substitute the new display when a selection is made. The last button clears the display by removing all inputs. The pushbuttons will be lighted to indicate the source of the current display selection and will be equipped with easily changeable labels to indicate the information available. These labels are normally prepared during the pre-mission set-up of the MOCR. The TVSM in combination with the distribution matrix will permit a console operator to connect his TVDM in parallel with any other TVDM. Thus, the Flight Director will be capable of observing the display which is active at any other console via his TVDM.

All TVSMs will be identical. If desired, access to certain inputs may be denied by removal of the connection between the TVSM and the appropriate control input at the distribution matrix..

5.3.3.4 Display Request Module (DRM)

The Display Request Module provides the means by which a console operator obtains a specific display format for presentation on his TVDM. Each request action will cause the display-control data processor to access a specific display subroutine and to select a converter channel for generation of the display which is then forwarded to the requestor's TVDM.

The number of subroutines for display data and number of resulting presentation formats which will be required is not fully determined at this time. The DRM permits access to the display/control data processor. It will only be installed at those consoles which have a need for such access. These will typically include the flight dynamics positions, the spacecraft systems monitoring positions, and the biomedical and environment monitoring position. A detailed definition of the DRM mechanism will require more detailed system design information, particularly in regard to number of display formats and programming techniques for the display/control data processing subsystem. A typical and available device for use as a Data Request Module uses a 5-by-6 array of 30 pushbuttons. Each pushbutton is identified by a caption which describes the action which results when the button is depressed. The 30 captions which are simultaneously in view constitute one set of descriptors. Captions are changed by changing the entire set simultaneously. Sixty-four sub-sets are provided. The mechanism is arranged to permit rapid change of descriptor sets. Such a change automatically causes the identity of the in-view descriptor set to become part of the code generated by pushing one of the buttons. Various techniques available for the rapid change of descriptor sets include slotted plastic overlays, rear projection of film strip frames and roll charts. It is reasonable to assume that access to computer-generated displays will be assigned by console function. Thus flight dynamics would not normally be able to request display formats pertaining to vehicle systems monitoring responsibilities. Restricted access will be accomplished by computer programming rather than by providing insufficient hardware for full control. As a matter of pre-mission set-up, it will be possible to change DRM and display/control data programming.

An investigation to determine the number and the complexity of display formats which must be accessed by MOCR personnel has been initiated. This will include some consideration of what display quantities could be combined into a simple format.

Two basic questions which affect the complexity of the display request instrumentation must be answered:

a. Will some of the data be presented in formats which will remain unchanged for a major phase of a single mission?

b. Will it be possible to control and monitor a major mission phase using a relatively small number of formats (such as 20 to 30 formats), or will the number required exceed the number of converter channels which can reasonably be provided?

If the answer to both these questions is "yes", the display mechanism can be much simplified by fixed assignment of display formats to converter channels. Basic formats would remain fixed during a major phase of a mission, and the display/control data processor would continuously update these displays without an external request. While such a system appears wasteful since converter channels are constantly in use and updated even though they do not always provide display outputs, its utilization would simplify the display operation by eliminating the Display Request Modules on the MOCR Consoles. Since all display outputs would be constantly available at the distribution matrix, they could be accessed by means of the TV Display Select Module alone.

Special display formats could still be available to the MOCR consoles by providing a means of accessing special request channels from the support areas. Such request would be made by means of the intercommunication system from the MOCR personnel to the support personnel who would control generation of special displays which could then be switched to the MOCR.

5.3.3.5 Event Sequence Indicator Module (ESIM)

Early, on-time, or late occurrence of various mission events will be displayed by event indicators. Flight dynamics and vehicle system monitoring positions will require the majority of such displays. Certain events will be of sufficient importance to be also indicated on other consoles and be repeated at the group displays. The number of event indicators will vary between operating positions. A preliminary sample listing of event indicators for the flight dynamics console has been given in Section 5.2.1, Table 5.2.1-1, for the launch and powered flight phases of a Gemini rendezvous mission.

Sequence Indicator Modules will vary in size and complexity with console function. A modular arrangement of two and three level indicator lights should be provided in the form of "lift-out" panels. Either split indicators with appropriate changeable captions for two and three levels or clusters of two and three lights may be employed. Data for control of the indicators will be carried in the display/control data processor. During the mission, the group of computer words containing light control bits will be read out of the data processor periodically or as special events take place. Equipment to set the indicator lights and to hold the setting until the next computer cycle may be installed external to the consoles or may be a part of the module itself.

A large amount of the input information to the event indicator data processing and display program will originate with spacecraft telemetry. In a number of cases, the information that an event has taken place is not only needed for mission monitoring, but must also be used to initiate data processing routines and other automatic responses. Certain events may be confirmed by voice communication from the spacecraft crew. Thus certain console positions may be equipped with a "Telemetry Event Override" capability built into their Event Sequence Indicator Modules. Applicable indicators will be combined with pushbuttons. This will permit the console operator to override the telemetry and indicator data processing by changing the event status if it should lag behind definite confirmation of event occurrence from sources other than telemetry.

5.3.3.6 Event Time Indicator Module (ETIM)

Correct initiation of IMCC responses, such as commands and recommendation to the GOSS and the spacecraft, depend upon accurate display of event times to operators. This function will be instrumented via an Event Time Indicator Module (ETIM) at each console. Each ETIM will consist of a panel containing selected groups of digital readouts arranged to show hours, minutes, and seconds. Capability will be provided for the computer to set each group. Some groups also have the ability to count up or count down in real time. For each of those, the computer will also have the ability to start it counting time, and to stop it. "Patch" connection, made during IMCC check-out and preparation, will determine whether a given timer counts up or counts down.

An example of the use of an ETIM is based upon the display requirements for the flight dynamics problem as discussed in Section 5.2.1. During a Gemini rendezvous mission, the personnel responsible for flight dynamics would require ETIM's on their consoles showing the following time display groups which count up:

a. Universal system time, (probably Greenwich Mean Time)
b. Mission elapsed time
c. Gemini elapsed time
d. Agena elapsed time

Also required are the following time display groups which count down:

a. Launch countdown, Titan/Gemini
b. Launch Countdown, Atlas/Agena
c. Time remaining in launch window
d. Time until retrofire for mission termination
e. Time until impact

The groups will be provided with identifying labels which can conveniently be changed. The setting, stopping, or starting of each group will be controlled by computer subroutines which can be prepared during IMCC check-out and preparation.

"Non-counting" time display groups will also be set under computer control. After setting, the devices must hold the indication until again set by the computer. Provision must be made to allow change of identifying captions on the non-counting time displays to allow for mission changes and evolution. The following example of the use of non-counting time display groups is also based upon the display requirements for the flight dynamics problem as detailed in Section 5.2.1 (Gemini rendezvous mission):

a. Next maneuver initiation time - Titan/Gemini
b. Next maneuver initiation time - Atlas/Agena
c. Estimated retrofire time for mission termination (becomes actual retrofire time)

Certain ETIM displays contain basic information of general interest to all MOCR personnel. Examples are universal system time, launch countdown for both vehicles, mission elapsed time, and time-until-impact. These quantities will be duplicated on a large-size ETIM, which is part of the group display instrumentation described in Section 5.3.5.

5.3.3.7 Communication Module (CM)

Although the voice intercommunication facilities located at the various MOCR and support area console positions are not discussed in this section, (Refer to Section 3.3.5.2) it should be pointed out that they can be considered as a functional part of display/control instrumentation. A large portion of the information on spacecraft and crew status and performance will be received via the space-ground voice links; correspondingly, a large amount of the IMCC actions and responses which are transmitted to the spacecraft will be transferred via the ground-space voice links. In a similar manner, the voice communication system will receive information from and transmit commands to the remote elements of the GOSS.

The communication module will consist of a panel which contains the type 112-key subsets which are the terminal equipment for the IMCC intercommunication system. All modules will be identical, but module capability will be tailored to the requirements of the console in which it is installed. As an example, capability to transmit over the ground-space link may be restricted or may require special clearance at certain consoles.

5.3.3.8 Command Initiation Module (CIM)

The command initiation module (CIM) provides the means by which a console operator directly initiates commands implemented by the computer. Actuation of the CIM causes the computer to access a specific command subroutine which controls the formatting, checking, and transmission of the command. The hardware implementation of the CIM may be similar to that recommended for the display request module (DRM) described in Section 5.3.4.3, since the function to be performed (communication with the computer) is similar and the recommended DRM instrumentation is very flexible and easy to operate.

Recommendations or commands which are implemented by the astronauts will be initiated by voice using the communication module (CM) described in Section 5.3.4.7. The CM will also be used to initiate the release of complex commands containing numerical parameters. Such parameters will be selected as a result of oral discussion between the FDO and his support personnel using their CM's. Actual entry of parameters into the computer will be performed by support area personnel using sophisticated on-line data entry devices such as message composers. Such devices can display formats, and allow editing and verifying command messages before entering them into the computer.

5.3.3.9 Status Monitoring Module (SMM)

The status monitoring module (SMM) is a panel containing computer-actuated status lights and digital readouts. The captions must be changeable to allow changes in mission goals. The operation of the lights and readouts is determined by the computer subroutine which controls them.

An example of the use of the SMM displays provided for flight dynamics personnel is based upon the requirements detailed in Section 5.2.1. Groups of digital readouts displaying status information could show:

a. Orbit capability - Titan/Gemini
b. Orbit capability - Atlas/Agena

c. Rendezvous approach - distance between vehicles
d. Rendezvous approach - rate of approach
e. Gamma (angle between missile velocity vector and local horizontal)
f. Velocity ratio
g. Predicted insertion altitude - Titan/Gemini (becomes current altitude Gemini after insertion)
h. Predicted insertion altitude - Atlas/Agena (becomes current Agena altitude after insertion)
i. Gemini apogee
j. Gemini perigee
k. Agena apogee
l. Agena perigee
m. Gemini orbit inclination angle
n. Agena orbit inclination angle
o. Predicted impact point - latitude
p. Predicted impact point - longitude

Other status indication not part of the Event Sequence Indicator Module (ESIM) consists of computer-controlled status lights. For flight dynamics personnel, status light groups may be:

a. Hold countdown - Titan/Gemini launch
b. Hold countdown - Atlas/Agena launch
c. Titan guidance; go or no-go
d. Gemini orbit; go or no-go
e. Atlas guidance; go or no-go
f. Agena orbit; go or no-go
g. Gemini abort request
h. Astronaut ejected; No. 1
i. Astronaut ejected; No. 2
j. Agena/abort request

Certain status information will be of general interest to all MOCR personnel. These quantities may be duplicated on a large-size status monitoring module which is part of the group display instrumentation.

Numeric values which are required infrequently will be computer generated upon request and displayed using the television display modules (TVDM's) described in Section 5. 3. 4. 1.

5.3.4 The Support Area Display Subsystem

This section discusses the support areas which are associated with each MOCR. These major support areas are designated as: (1) flight dynamics, data monitoring and analysis, (2) spacecraft systems data monitoring and analysis, and (3) biomedical and environment data monitoring and analysis.

In general,these support areas will have the following responsibilities:

a. To respond to requests for special information made by MOCR personnel; this information may be supplied wholly from within the support area or with aid from devices outside the area, such as data processors

b. To monitor such input data to the IMCC as is deemed necessary and alert the MOCR personnel whenever potentially hazardous or hazardous conditions are detected

c. To provide detailed analysis of problem situations at the request of MOCR personnel

d. To supply detailed information on spacecraft systems and trajectories, as the case may be, during contingency situations; an example might be the tracing of the source or implication of a malfunction by means of schematic diagrams.

Analysis presently in progress will detail the responsibilities of each support area. For the purposes of this document,the foregoing assumptions furnish the basis for the support area equipment descriptions which follow.

5.3.4.1 Flight Dynamics Support Area

The primary function of this group will be to support the Flight Dynamics Officer and his assistants. Information pertaining to abort plans, optimum orbital trajectories and trajectory maneuvers, alternate or emergency commands and predictive data, will be supplied by this support group. Display equipments in the flight dynamics support area shall include but not be limited to the following:

a. Television Display Modules. TVDMs will permit the viewing of displays generated by the computer. Five TVDM's are postulated at present. Associated with the television displays will be digital to TV converters (three) and display request modules such as those provided in the MOCR consoles.

These monitors may be arranged in consoles as in the MOCR, rack mounted, or ceiling suspended.

b. Plotters. Plotters will be required to provide hard copy (and working copy) print-outs of problem solutions. These plotting surfaces will also be driven by computer output through D/A conversion. Examples of the type of plot are trajectory prediction plots and plots of alternate transfer maneuvers during rendezvous. Plotting surfaces may be upright (vertical) or horizontal.

c. Digital Readouts. Readouts varying from three to eight digits will be required to display numerical quantities such as apogee, perigee; eccentricity; times (GMT, GET, next maneuver, etc.); coordinates x, y, and z, both predicted and actual; latitude; longitude; etc. These displays will be driven by the computer and by the timing system and will be located strategically to afford maximum viewing.

d. Event and Status. Indicators will be required to inform the support personnel of certain event and status information. These lights will be paralleled with corresponding lights in the MOCR and are required to inform support personnel of mission progress.

e. Television High-Resolution Cameras. TV high-resolution cameras will be used for communication with the MOCR personnel. Two such cameras will be located in the Flight Dynamics support area, arranged in such a way that work material (plots and charts) may be viewed by the camera under proper lighting conditions. The outputs of these cameras will be available to the MOCR distribution matrix and will be readily accessible.

f. Alpha-Numeric Printers. Alpha-numeric printers will be required as an output device directly associated with the computing facility. It is envisioned that some problems that might occur will require computer solution.

g. Data Entry. Since it is likely that not all contingencies can be planned for, a means of computer entry and exit will be provided. An electronic typewriter, tape punch, or sophisticated message composer to facilitate machine entry might be used. Such devices would be used by support personnel to solve the problem while the MOCR personnel remain free to monitor developments.

5.3.4.2 Spacecraft Systems Support Area.

The function of the support group is to aid the Spacecraft Systems Officer and his assistants in their decision-making processes. Information pertaining to the operational systems of both the Atlas/Agena and the Titan/Gemini shall be provided to the SSO by this group.

The display equipments that are envisioned for this area are:

a. Television Display Modules. TVDMs will provide for the viewing of computer-generated trend information and telemetry summary displays. Associated with five TVDMs will be three digital-to-TV converters and a Display Request Module (DRM). An example of a display that might be viewed would be a predictive trend of oxygen expenditure, fuel expenditure, or other expendables. Computer-aided calculations would determine a rate of expenditure from telemetered data and apply this rate in constructing a display to show future expenditure against time. Television monitors may be console-mounted, rack mounted, or ceiling suspended units.

b. Plotters. Plotters will be required to provide hard copy of plots and trends. Previous remarks made in the Flight Dynamics Section concerning plotters apply. The type of plot would be similar to that presented by the TVDMs, but in hard copy form. Such hard copies provide working material which may be interpreted for the Spacecraft Systems Status Monitor by support personnel.

c. Chart Recorders. Chart recorders will be used to provide historical records and hard copy of telemetered parameters. Certain parameters will be monitored and interpreted continuously, and chart recorders are a convenient and inexpensive method of providing hard copy records. The recorders may be arranged in rack mounts with multiple channels displaying several parameters simultaneously.

d. Meters. Meter panels will be required to allow monitoring of telemetered data in near real time. In the main, the metered parameters will be the same as those recorded on strip charts. The displaying of these quantities on meters, with simultaneous recording, permits rapid interpretation of the telemetered data from familiar meter displays.

e. Event and Status. Indicator lights will be required to inform the support personnel of certain event and status information. These lights will be paralleled with corresponding lights in the MOCR and are required to inform support personnel of mission progress.

f. High-Resolution Cameras. High-resolution cameras will be required for communication with the MOCR personnel. Two such cameras will be located in the spacecraft systems support area, arranged such that work material (plots and charts) may be viewed by the camera under proper lighting conditions. The outputs of these cameras will be available to the MOCR distribution matrix and will be readily accessible.

g. Alpha-Numeric Printers. Alpha-numeric printers will be required as an output device directly associated with the computing facility. It is envisioned that some problems that occur will require computer solution.

h. Data Entry. Since it is possible that not all contingencies can be planned for, a means of computer entry and exit will be provided. An electronic typewriter, tape punch, or sophisticated message composer to facilitate machine entry might be used. Such devices would be used by support personnel to solve the problem while the mission controllers remain free to monitor developments.

5.3.4.3 Biomedical and Environmental Data Monitoring and Analysis Support Area.

This support group is responsible for aiding the Biomedical and Environment Monitor in his decision processes. Information pertaining to the well-being of the crew (medical parameters) and crew environment (capsule systems) shall be furnished by this group.

The display equipments required in this support area are:

a. Television Display Modules. TVDMs will permit viewing of medical and system trend displays, as required. Associated with the five monitors will be three digital to TV converters and a Display Request Module (DRM). It is envisioned that this capability will be used to predict future performance based on present and historical data. The TVDMs may be arranged in consoles, rack mounted, or as ceiling suspended units.

b. Plotters. Plotters may be required for producing hard copy of computer-generated predictive displays. Plotting surfaces may be upright or horizontal. Associated with the plotters will be digital to analog conversion equipment.

c. Strip Chart Recorders. Strip-chart recorders will be required to provide hard copy of the telemetered biomedical and environmental parameters. It is expected that these shall be used as interpretive copy in the event of contingencies. These recorders may be arranged in rack mounts with multiple channels displaying several parameters simultaneously.

d. Meters. Meter panels will be required to allow monitoring in near real time of telemetered data. In general, metered parameters will be the same as those recorded on strip charts. The displaying of these quantities on meters, with simultaneous recording, permits rapid interpretation of the telemetered data from familiar meter displays.

e. Event and Status. Indicator lights will be required to inform the support personnel of certain event and status information. These lights will be paralleled with corresponding lights in the MOCR and are required to inform support personnel of mission progress.

f. High-Resolution Cameras. High-resolution cameras will be used for communication with the MOCR personnel. Two such cameras will be located in the Biomedical area, arranged in such a way that work material (plots and charts) may be viewed by the camera under proper lighting conditions. The outputs of these cameras will be available to the MOCR distribution matrix and will be readily accessible.

5.3.5 Group Display Subsystem

5.3.5.1 General

Five large scale display surfaces are proposed for each MOCR. These group displays are recommended for the presentation of information on mission status and system status in real, near real, and future time. Four of the displays will be implemented by using projection techniques. One display, GOSS status, seems to lend itself more readily to a fixed, non-projection technique. By using projection devices for the majority of the group displays, it will be possible to maintain the required flexibility. In addition to flexibility, programmability is most easily realized with projection devices. A survey of available group display equipment for projection techniques is provided in Appendix 5A. Placement and configuration of the display surfaces is discussed in Section 5.3.6.

5.3.5.2 Summary Mission Status Display

Generation of a meaningful summary display for rendezvous and lunar missions presents a formidable problem. Ideally, a space-coordinate display should be provided. Any display of space coordinates implies a third dimension. None of the available techniques for presenting simultaneous x, y, and z coordinate information on a two-dimensional display surface appears satisfactory for use in the MOCR summary mission status display.

The proposed solution would consist of a precision, two-dimensional, composite display which can be programmed to provide either a single two-dimensional display utilizing the full 2 to 1 aspect ratio of the center screen or two separate two-dimensional displays side-by-side having 1 to 1 aspect ratios. One application of the 2 to 1 aspect ratio full screen display would be presentation of a map reference projection of the earth with the sub-satellite track of both spacecraft in real time. This display would be similar in appearance to the central mechanical display in the Mercury Control Center. At the option of flight control personnel, predicted impact points for any given time of retrofire could be displayed. The ability to switch the display into two 1 to 1 aspect ratio displays would be used to show spacecraft positions in other coordinate systems. Any two-dimensional combination of coordinates could be utilized on one display while a second set of coordinates would be presented on the adjacent display. Synchronized event markers would appear on both displays. Interpolation between the dual two-dimensional presentations will allow observers to extract three-dimensional data in real time based upon computer outputs.

For the Gemini missions, it is visualized that overall mission progress and status would be presented in a two-to-one aspect ratio. This display would typically show, as background, a world map in full color. Superimposed on the map would be the current tracks or paths of both the Gemini and Agena vehicles. Shown on each track, probably at the extreme left, would be a vehicle identifier and orbit number. The track would proceed across the screen in as near real time as is possible, that is, the leading edge of the track would represent present position as closely as can be depicted within a nominal deviation. Ahead of the track, a light spot will indicate impact point if an abort occurred at that particular instant. Events such as impulse applied, rendezvous complete, disconnect, reentry initiated, etc., can be marked with unique symbols either on the tracks or adjacent to them. These marks shall remain on the display for the duration of that track. (An event symbol legend shall appear on the world map projection.)

The devices necessary to accomplish the above would typically be (1) a background projector to project the world map color slide, (2) two Kollsman Instrument Corporation projector systems to draw the vehicle tracks and (3) a number of servo-driven light spot projectors with symbol masks. (The inherent flexibility of this combination of computer-driven display equipment will make it easily adaptable to Apollo display formats. For Apollo missions, the reference slide projector would present full color outline or earth maps in different scales, earth-to-moon reference backgrounds or lunar maps.) The computer-driven, servo-controlled light spot projectors would show dynamic non-permanent data such as current spacecraft position and predicted landing area if the mission were aborted. The light spot from each projector is shaped by a slide to represent the subject. The computer-driven Kollsman displays would be used for dynamic permanent data such as trajectories and tracks, event notations, and mission history. These devices consist of servo-controlled scribers which scratch clear lines on opaque slides while the slides are being projected. An eight-position, remotely-controllable color wheel in the light beam of each projector allows choice of color for the resultant bright-line displays. The slides are scribed on portions of a glass disc which may be rotated to display a new subject. The glass disc in each projector has the capability of holding 20 different subjects (20 disc positions). Manual changing of discs is used when more subjects are required. Thus, the summary Mission Status Display will be a dynamic, full-color display adaptable for both Gemini and Apollo formats.

5.3.5.3 GOSS Status Display

This is a fixed non-projection display based on a technique used for the Defense Communication Control Center. The display will show all remote sites, launch and recovery control centers, and the interconnecting communication channels on a world map. Light piping and light matrix techniques can best be employed to show the status and readiness of the various facilities. The display could be actuated manually, or driven directly from site status reports received via the Communication System.

The display is made up of several simple devices. The display area is a laege translucent panel upon which an outline map of the world appears. Behind the panel at each GOSS network station, a group of computer-controlled colored lamps or small projection digital readout can be mounted. Operation of these lights and readouts will be visible through the translucent screen to show the current status of each station. Plastic light pipes, easily bent to required shapes will also be mounted behind the panel to indicate status of the communication links between stations. Color coding will indicate the degree of availability of each link.

This implementation allows neat, inexpensive changes as GOSS network stations or communication facilities evolve. Information conveyed will be:

a. Communication Routing: The communication routes will be depicted with indications as to type (hi-speed, lo-speed, TTY, Radio, etc.) and the status line shown.

b. Station Status: An indication of the station status (standby, operative or non-operative) shall be given.

c. Vehicle Contact: An indication shall be given for each station to show when that station is in contact with the vehicle. This indication will distinguish between contacts with Gemini or Agena.

d. Station Equipment Status: An indication shall be given of the status of major equipments of each station.

5.3.5.4 Television Projection Displays

The display system concept described in Section 5.3.2 uses ultra-stable, high resolution television to distribute much of the data in the IMCC. Computer-generated graphs, tables, and text; support area generated drawings, slides, and scenes; and actual pictures of the launch area and, in later missions, spacecraft television will be available via the television distribution system.

Data of general interest, such as vehicle launches, scenes, and telemetry tabulations will be shown on a 3 to 4 aspect ratio screen using television projection. For operational use during a mission, any video information available in the MOCR may be presented on the large screen. Thus, in addition to providing displays of general interest, projection television will be valuable in supplementing console displays of interest to a particular group such as biomedical and environmental, vehicle systems, or flight dynamics. The wide variety and amount of use intended for projection television will be enhanced by provision of two separate large screen TV displays.

Currently available hardware includes the General Electric "Light Valve" and the Theater Network Television "Eidophor". The Eidophor is superior in image quality control and light output. In either version, a vacuum pump exhausts a chamber containing an electron gun and an oil-covered surface. The device is operated like a cathode-ray tube with the electron beam deflected and intensity controlled in the normal television manner. The electrons strike the oil film, charging it. Electrostatic attraction deforms the oil film, proportionally. The oil film is in the projection light path. If no deformations exist in the oil film, a grid of slits and bars prevents light from reaching the display screen. Where deformations of the oil film exist, the oil refracts the light past the pattern of bars into the slits where it can reach the screen. The oil film deformations quickly disappear so that the next frame may be generated at standard television frame rates to prevent flicker.

5.3.5.5 Optical Plotting Projection Display

The fifth display surface, provided in the Mission Operations Control Rooms will be served by an optical plotting projector system identical to that described for the central summary Mission Status Display in Section 5.3.5.2. It may be utilized as a launch display. It may also perform functions similar to those provided by the plotting boards in the Mercury Control Center. During the mission, it can be employed to display trends by showing a variety of function plots and to back up the Summary Mission Status Display.

5.3.5.6 Recommendation to Limit Types of Group Display Projection Equipment

For ease of maintenance and flexibility of use, it is recommended that the number of different types of MOCR projection display equipment be limited. The Summary Mission Status Display, Optical Plotting Projection Display, and Television Projection Displays described in the preceding paragraphs, represent two different requirements and will be implemented by two types of equipment. This also provides redundancy for reliability, since each display provides backup for the other set of identical instruments, and inputs can easily be switched between them.

5.3.5.7 Time and Status Group Displays

In Section 5.3.4, a detailed discussion of Event Sequence Indicator Modules, and Status Monitoring Modules for consoles is given. Many of the sequence light, elapsed time, times-to-go, and status light displays representing overall mission will be of sufficient general interest to merit their duplication in large form as group displays.

The devices used for group display will actually be physically larger versions of the digital readouts and lights used on the display consoles. These devices, together with appropriate identifying signs, will be located above the MOCR projection display screens.

5.3.6 Mission Operations Control Room - Design Considerations

5.3.6.1 General Design Objectives

The Mission Operations Control Room (MOCR) will house the monitoring and Control personnel and the equipment necessary to establish a working man-machine relationship. Specification of personnel responsibilities in the MOCR, specification of the interface equipment, and specification of room configuration and facilities must be carefully done to ensure meeting mission control requirements.

a. MOCR Manning. The determination of the identity and number of personnel in the MOCR during a mission is based upon consideration of the operations to be performed. A specific manning concept for both Gemini and Apollo missions is described in WDL Report TR114-2 and reiterated in Section 5.3.6.2.

b. MOCR Man-Machine Interface Equipment. It is the objective of the MOCR design to specify equipment which makes the desired data reliably and rapidly available in a form which aids understanding by monitoring and control personnel. Sections 5.1, 5.2, and earlier portions of this section describe visual display equipment which satisfies these objectives, is compatible with data entry and data processing techniques, and is flexible enough to accommodate changes in MOCR manning and mission goals. In the MOCR these visual displays are of two types: physically large displays intended for simultaneous viewing by a group, or physically small displays mounted on consoles for viewing by one or two people. The objective is to specify an equipment mix which makes best use of the following advantages of each type:

   1. Group display properties advantageous in the MOCR:

      (a) Where information requirements of a number of viewers are similar or identical, a group display can reduce the total amount of equipment in the system compared to providing multiple individual displays.

      (b) A working group can coordinate efforts and communicate more effectively since it is assured that each is seeing exactly the same display.

      (c) The group display provides a feeling of continued participation for temporarily idle console operators and visitors, avoiding a feeling of isolation.

2. Console display properties advantageous in the MOCR:

   (a) Information may be displayed which exactly fits the task requirements of the console operator rather than a composite display not optimized for everyone.

   (b) Displays can be changed at will to gain access to different information without interrupting others.

   (c) The deployment of personnel and equipment has more flexibility than for group displays.

Section 3 describes the aural communication equipment which utilizes communication modules (CM's) based on 112-key subsets. This is not consistent with the present state-of-the-art which makes it necessary to convert computer-generated data to visual outputs only.

Inputs from man to machine are still limited to physical movements of analog position devices and digital keys or switches. Section 5.2.2 details some of these control techniques. Presently, no requirement for "group controls" is foreseen. This means that all controls will be on consoles and will be operated by individuals working independently.

From this brief summary of the man-machine interface equipment, it can be seen that the choice of equipment mix has the following effects upon MOCR design:

1. The designer has latitude in placing equipment not connected with group displays. The objective will be to place as much equipment as possible outside the MOCR. The arrangement of the console-mounted equipment inside the MOCR is limited only by human engineering considerations.

2. The group display equipment choice limits the placement of men and their consoles, no matter which type of equipment is chosen. This is the result of the two-dimensional nature of these displays.

3. Equipment which seriously deteriorates man's working environment by the generation of excessive noise, fumes, heat, etc. must not be placed inside the MOCR.

c. <u>MOCR Room Configuration and Facilities.</u> In addition to merely providing space for personnel and equipment, the room must fulfill other important requirements:

1. It must provide a comfortable working environment for the monitoring and control personnel. This includes temperature and humidity control, proper lighting, easy access to an operator by his support personnel without interfering with other operators, easy access by operators to service areas such as washrooms and drinking fountains, and an esthetically-pleasing room appearance.

2. It must provide a similarly comfortable environment for observers and visitors. For this reason, attention directed toward providing a pleasing appearance is considered necessary.

Specific room configuration and facility designs are discussed in Section 5.3.6.3.

5.3.6.2 MOCR Organization Structure

The manning concept for the MOCR has been developed from a consideration of the functions to be performed during the various phases of Gemini and Apollo missions. The concept is based upon the detailed flow of information required during these phases and on design considerations for processing such information. Recommended criteria for deciding operating assignments inside the MOCR are:

a. All activities for the various phases of a mission which require direction of final decisions should be directed by a person located in the MOCR. Thus, the Flight Director and all personnel reporting directly to him will be located in the MOCR. This will also insure that, during an operation, the Flight Director does not normally have to deal with individuals in remote areas, but can directly query personnel in the MOCR. Staff area activities or functions which directly support personnel in the MOCR are to be located in "support areas" in close proximity to, but outside of, the MOCR.

b. Activities which require knowledge of the entire mission or the current status of the mission to interpret information concerning spacecraft location, spacecraft systems, and mission events will be directed by an individual in the MOCR. For example, the individual who normally has a responsibility to talk to the astronauts must be located in the MOCR.

c. Activities which require closely-interrelated action by more than one individual for control of major events will make it desirable to locate these personnel together in the MOCR. The resultant direct communication allows operators performing functions which require the close attention of many to make quicker and more accurate interpretations of the situation than would be possible if communication was more difficult.

Support areas outside the MOCR will be connected to each other and to the MOCR by voice and video links to maintain the close communication required between these areas.

Based upon evaluation of the missions to be performed, a tentative staffing of the MOCR has been developed. For the Gemini rendezvous mission, the personnel at console positions in the MOCR, will be:

a. Operations Director
b. Network Commander
c. Recovery Commander (located adjacent to MOCR)
d. Flight Director
e. Assistant Flight Director
f. Operations and Procedures Officer
g. Network Status Monitor
h. Spacecraft Systems Officer
i. Spacecraft Systems Status Advisor: Agena
j. Spacecraft Systems Status Advisor: Gemini
k. Spacecraft Communicator
l. Flight Test Assistant
m. Biomedical and Environment Monitor (Flight Surgeon)
n. Flight Dynamics Officer
o. Assistant Flight Dynamics Officer for Titan/Gemini
p. Assistant Flight Dynamics Officer for Atlas/Agena

A discussion of the functions and organizational responsibilities of these men is given in the "Gemini Rendezvous Information Flow Plan," WDL-TR-E114-2, 9 July 1962. Suggested assignments to specific consoles are shown in Section 5.3.6.3.

Based upon a separate evaluation of the missions to be performed, a tentative staffing of the MOCR has also been developed for Apollo earth and lunar missions. Personnel, at consoles in the MOCR during those missions, will be:

a. Operations Director
b. Network Commander
c. Recovery Commander (located adjacent to MOCR)
d. Flight Director
e. Assistant Flight Director
f. Operations and Procedures Officer

g. Network Status Monitor

h. Spacecraft Systems Officer

i. Spacecraft Systems Status Advisor: Command and Service Modules

j. Spacecraft Systems Status Advisor: Lunar Excursion Module

k. Spacecraft Communicator

l. Flight Test Assistant

m. Biomedical and Environment Monitor (Flight Surgeon)

n. Flight Dynamics Officer

o. Assistant Flight Dynamics Officer for Command and Service Modules

p. Assistant Flight Dynamics Officer for Lunar Excursion Module

A discussion of the functions and organizational responsibilities of these individuals will be given in the "Apollo Information Flow Plan," WDL TR-E121.

From the standpoint of the MOCR room designer, these personnel assignments are identical since they each have the same number of console operators using the same consoles and group displays. (The display system has the capability to adapt easily to the changes in mission.)

5.3.6.3 MOCR Arrangement

Section 5.3.6.1, on general design objectives, lists several factors which influence MOCR physical configuration. The effects of these factors upon room arrangment are interrelated, and in many cases requirements conflict. Thus, the final arrangement must be a compromise. Many arrangements have been suggested and evaluated. Only the three, which appear to adequately satisfy requirements, are shown and described in this section.

a. Similarities in Recommended Room Arrangements. Although recommended room arrangements differ in several respects, they have very much in common:

1. Air Conditioning, Heating, and Ventilation. Air conditioning, heating, and ventilating will provide an environment continuously suited to human comfort. Adequate air conditioning must also be provided for electronic equipment.

2. Lighting. One of the conflicts is that operators must have enough light to work at their consoles and move around, yet they must clearly see their displays. It is not considered desirable to have a darkened MOCR with individual illumination for each console. It is recommended that sufficient lights be provided to establish a general illumination level of 25 foot-candles measured 30 inches above the floor in console areas. Partially directional fixture arrangements, dark floor covering, and dark backs on consoles may be desirable to reduce room ambient light falling on the large screen displays to 5 foot-candles or less. The recommended large screen display equipment will produce very good contrast under these conditions.

3. Access and Foot Traffic. Support and service areas are located immediately adjacent to the MOCR. Consoles are arranged so that a minimum of 4' - 6" is provided for an operator's chair and walking space behind each console. The arrangements are such that it is not necessary to walk behind more than one operator to gain access to any console position.

4. Cable Ducts and Conducts. Cables and interconnections between equipments will be run under raised modular floors.

5. Observers and Visitors. Comfortable seating with an adequate view of large displays and console operators is provided at the rear of the MOCR in a glassed-in room.

Separate rooms are provided at the rear for observers controlling simulation exercises and the distribution of mission information to the public. In the illustrations that follow, the location of the simulation control area differs from that in TR-E112-2 and is shown here as an alternate, improved location.

6. Several Floor Levels. To prevent any obstruction of an operator's view of the large screen displays, the floor levels are designed so that consoles at the front of the viewing area are lower than those at the rear. This technique is extended into the observer and visitor areas.

7. Total Physical Space. The total floor area and ceiling height devoted to display equipment space, projection space, support area space, main MOCR operating area, visitor space, and observer space is the same for all arrangements and is adequate for expansion.

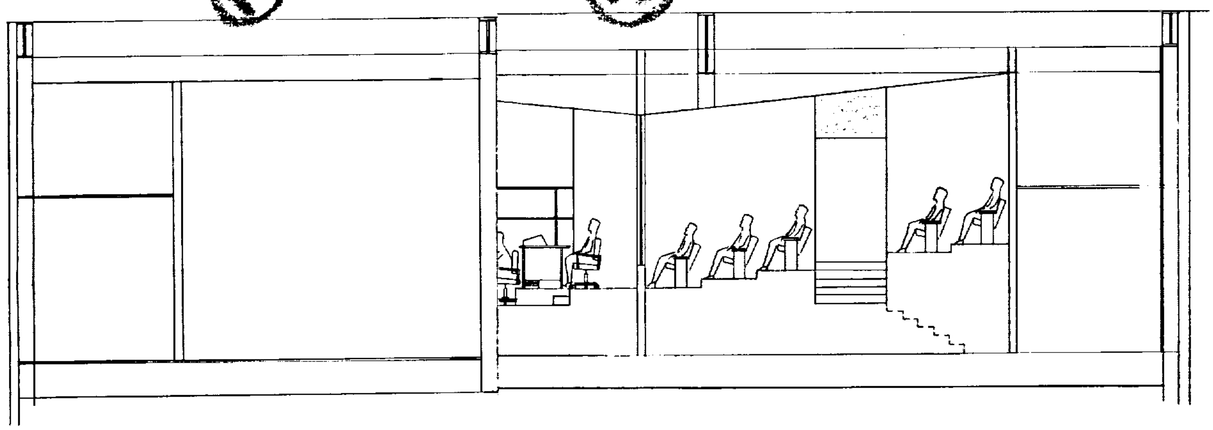
b. Differences in Recommended Room Arrangements. The different arrangements are the result of consideration of the following two questions relating to the large screen displays:

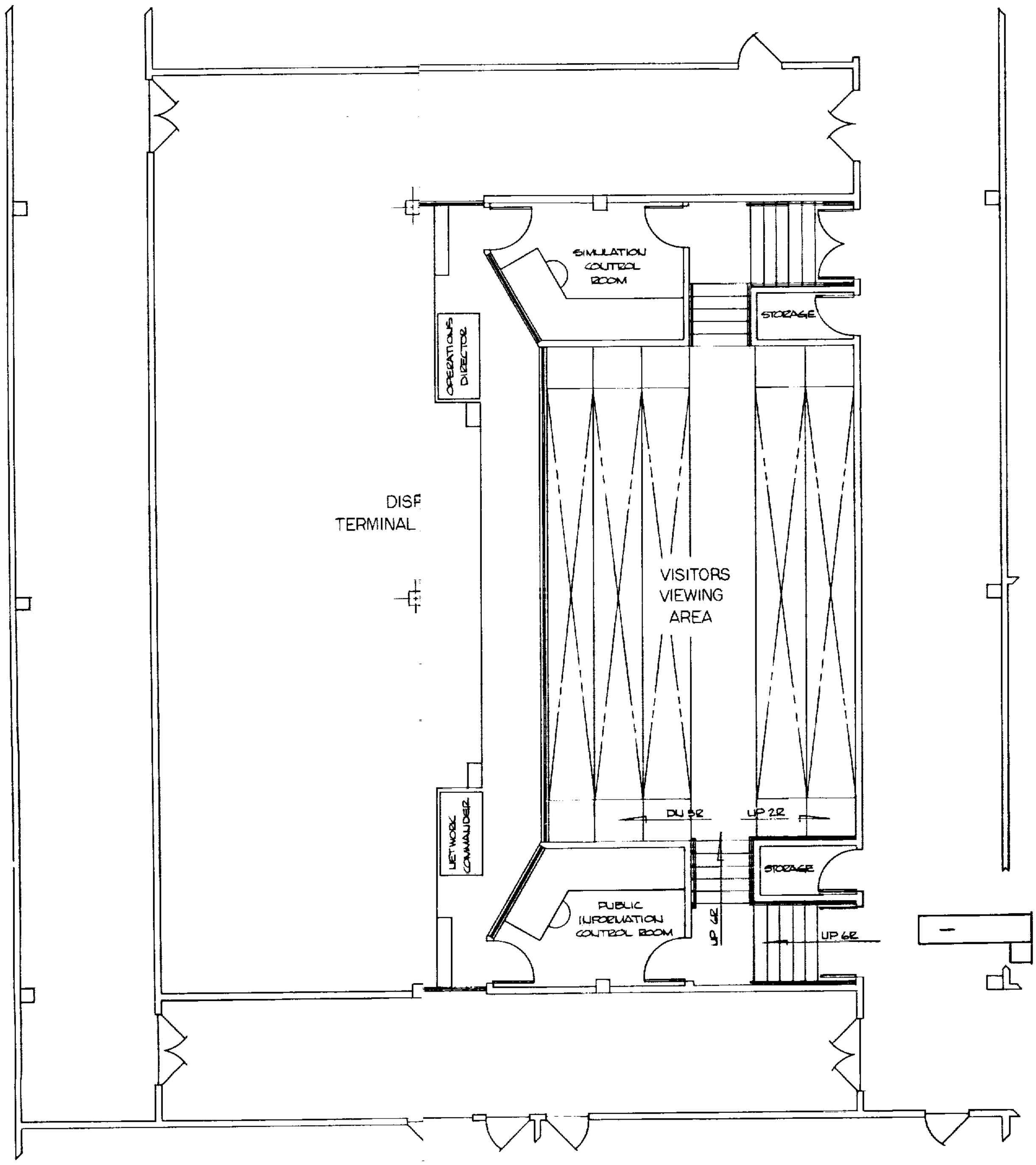
1. Is it necessary that every operator in the MOCR, every observer, and every visitor have a good viewing position for all group displays?

2. Will the saving in group display projection space permitted by front projection justify the reduction in display contrast compared to rear projection?

Figure 5.3.6.3-1 shows a room arrangement with each console labeled to show which operator sits at that console during a Gemini mission. The large screen techniques utilize rear projection for four of the screens. (The fifth large screen is not a projection display.) A careful analysis of viewing angles, light output from projectors, bend angles, and available screen materials has led to console positioning which allows every console operator, observer, and visitor a clear view of all screens without a "hot spot" on some screens and does not require a viewer to turn his body to see the displays. Space is provided for the addition of more consoles if future needs dictate. The entire free span area in the room is utilized for display with a combined display screen width of 60 feet. A large visitor area (seating for 75 plus additional space) is provided. The visitor area is arranged so that each visitor has a clear view of MOCR operations, yet the visitors are physically separated from operating personnel by a glass

A B




SIMULATION CONTROL ROOM
STORAGE
OPERATIONS DIRECTOR
DIS
TERMINAL
VISITORS VIEWING AREA
DN 3R
UP 2R
NETWORK COMMANDER
STORAGE
PUBLIC INFORMATION CONTROL ROOM
UP 6R
UP 6R

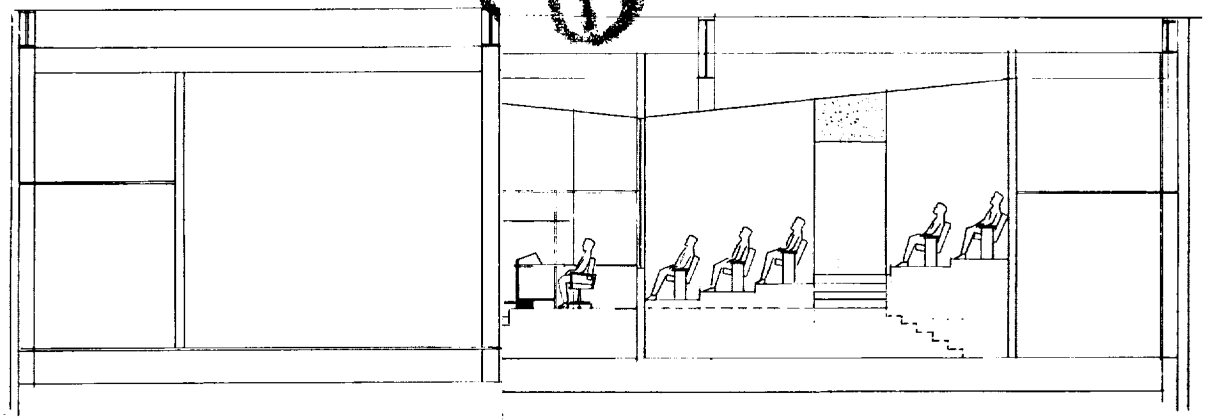
partition. Halls on each side allow direct access to operating positions. Straight line console layouts allow use of common cable troughs below the raised floor to ease cable servicing and installation.

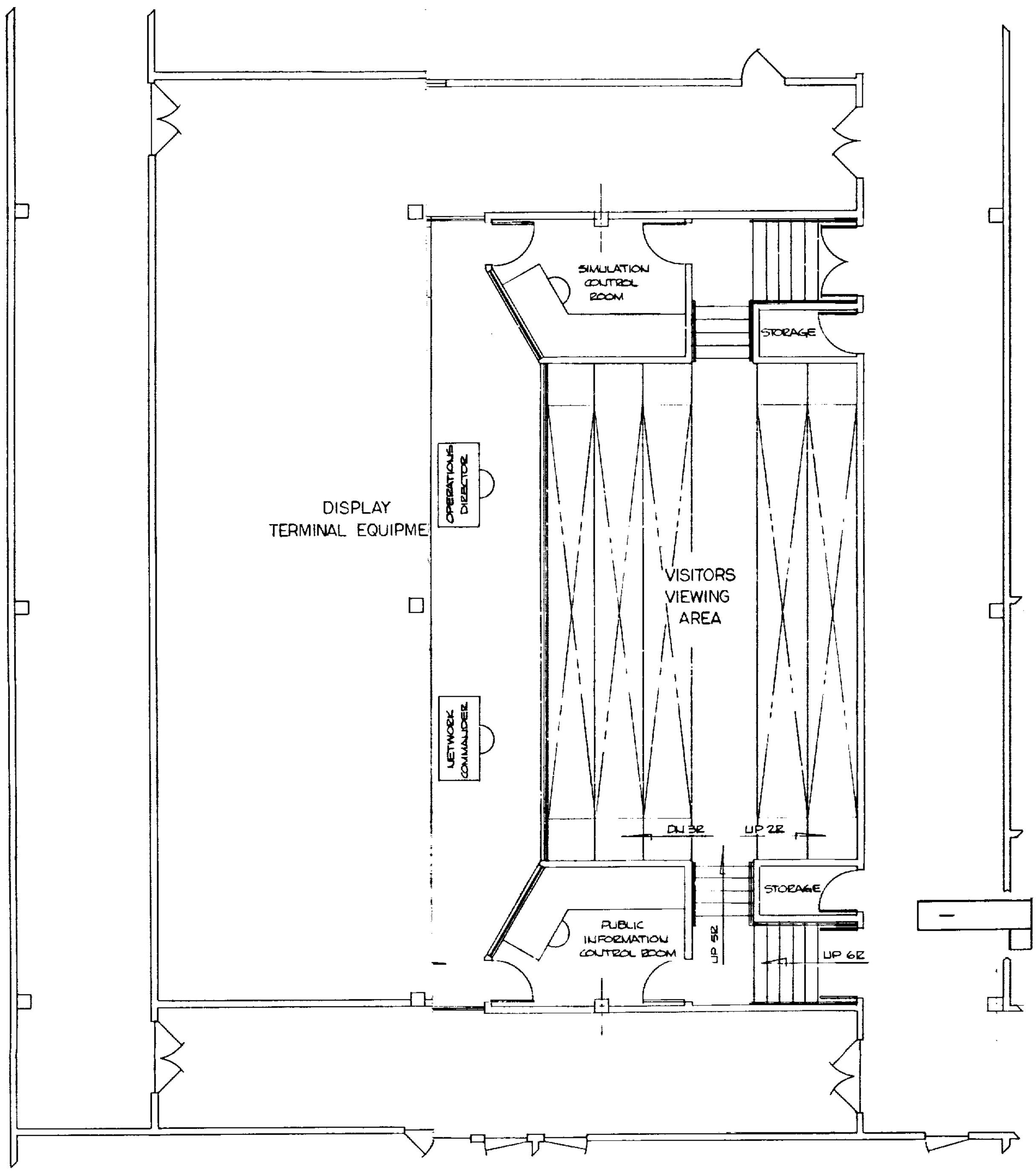
Figure 5.3.6.3-2 shows another rear projection arrangement. It illustrates that if some of the large screen displays are outside the scope of interest of some operators, they may be behind or beyond the best viewing angles for those special consoles. Thus, most of the vacant space of Figure 5.3.6.3-1 is usable if the mission grows to require consoles of this type, or if it becomes desirable to bring additional support area personnel into the MOCR.

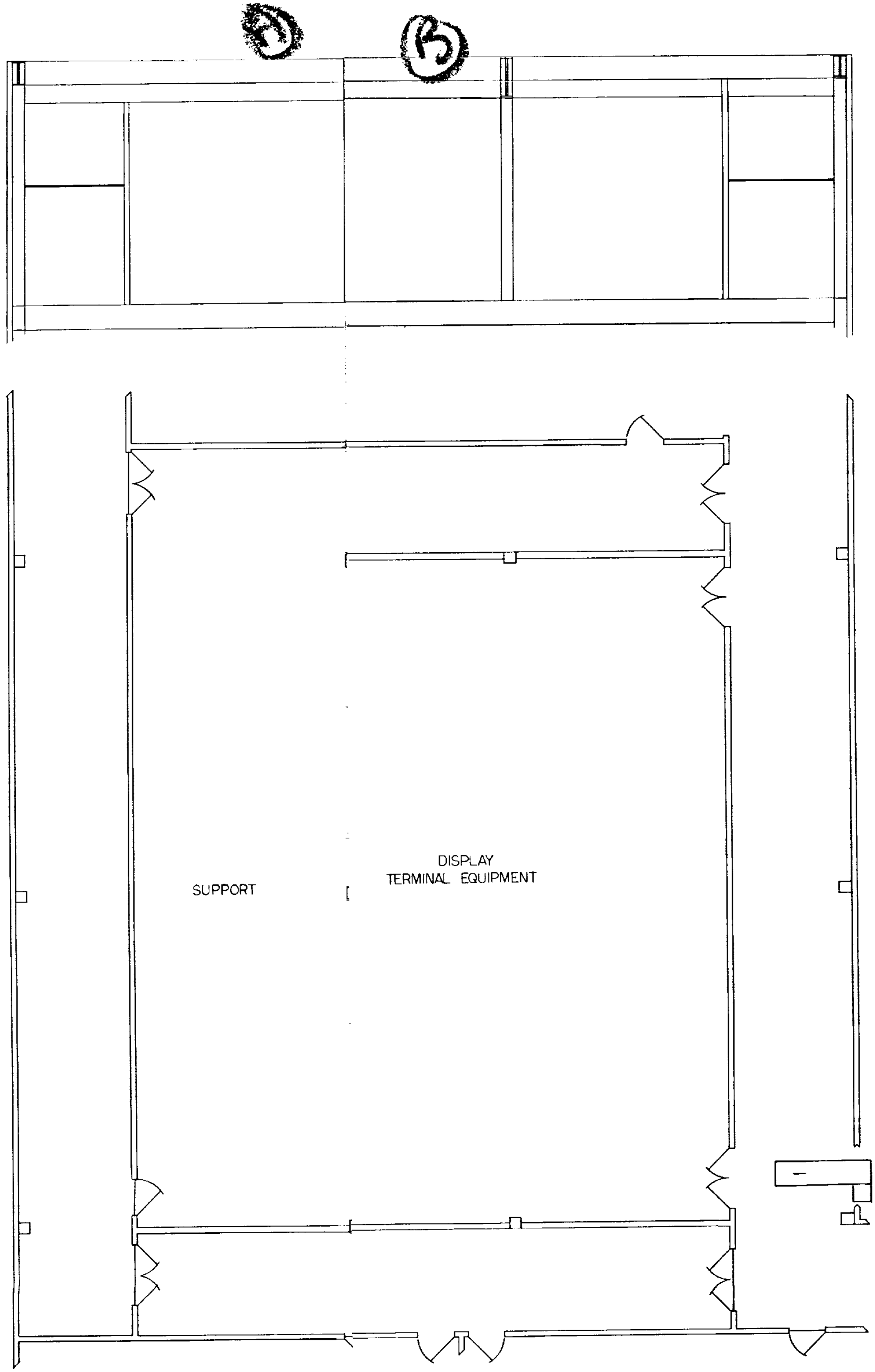
Figure 5.3.6.3-3 shows a front projection layout. Instead of sharing the space for the projector light beams with the projection equipment, the space for the light beams is shared by the MOCR main operations room. This increases available floor space somewhat since the projection rooms can be smaller and it allows more of the area immediately adjacent to the MOCR to house support functions. It also introduces problems. The higher reflectivity of front projection screens will reduce display contrast by at least a factor of four to one compared to rear projection. A minor problem is that cigarette smoke will become visible in the projector beams.

From an esthetic point of view, it is considered desirable to eliminate any effect which would draw the attention of the observer to mechanisms involved in group display generation. Thus, the appearance of a display "wall" showing a group of images is desirable. It is further desirable that a display surface present a neutral dark appearance when not in use. These considerations, in addition to technical reasons, have led to the recommendation of rear-screen projection techniques.

There are many possible variations of MOCR arrangement. Facility design criteria have provided adequate space for most reasonable designs. In addition to the arrangements selected for inclusion in this report, others will no doubt evolve as analysis progresses. The decision as to which will be recommended prior to the final report will be a difficult one, since in many cases, there will not be an identifable




SIMULATION CONTROL ROOM
STORAGE
DISPLAY TERMINAL EQUIPME
OPERATIONS DIRECTOR
VISITORS VIEWING AREA
NETWORK COMMANDER
DN 3R
UP 2R
STORAGE
PUBLIC INFORMATION CONTROL ROOM
UP 5R
UP 6R



A
B
SUPPORT
DISPLAY
TERMINAL EQUIPMENT

"wrong" or "right" solution in an engineering sense. Instead, the solution of the problem will lie in the proper weighting of the relative advantage and disadvantage of the largest number of reasonable approaches. An analytical method which has been initiated to compare the various facets of each system to arrive at a proper solution is described below:

a. List all parameters which affect the selection of the proper system. Examples of such parameters in our particular problem are: image quality, proximity of support areas, relative cost esthetic appearance, and others.

b. Weigh or grade the parameters according to their relative importance in achieving the best solution. Thus in these cases, the image quality might be twice as important as the proximity of the support areas.

c. Rank the competitive systems in each category, giving the best systems the greater number of points.

   Thus, in the case of image quality where rear projection is probably better (for a given set of conditions), rear projection would score 2 and front projection 1. Where systems are equal, score each 1-1/2.

d. Multiply the rankings by the weighting factor in each category.

e. Total the products obtained in step d for each system, The system with the greater total is considered the better one.

There are two problems in applying the above method to achieve a proper solution. These are:

a. The exclusion of parameters which affect the problem solution or the inclusion of parameters which do not.

b. The possibility of bias appearing on the selection of proper weighting factors.

The first problem will be circumvented by having several experts independently draw up parameter lists and then, as a group, decide upon the final list to be used. This method will ensure that the majority of parameters is included, and group discussion of individual lists would eliminate extraneous items. The second problem is more difficult to solve than the first; however, here again the use of several independently developed lists and weighting factors would serve as a guide to relative importance, and group discussion by experts should generate a realistic set of weighting factors. Another way of solving the problem would be to perform many iterations, each using a different set of reasonable weighting factors since it might turn out that no matter how the parameters are stacked (again, within reason), one design will be superior.

APPENDIX 5A
CONSIDERATIONS OF AVAILABLE DISPLAY HARDWARE

This appendix contains a detailed listing of the characteristics of display hardware which will be available during the IMCC construction period (1963) and which may be driven by a digital computer. For convenience of application, the equipment is first broken into two general types: console display equipment and large group display equipment. Although these two categories are sufficient to describe IMCC display hardware, a third category has been set up for "three-dimensional" displays to allow a more concise discussion of the unique problems of such displays. Each of the three classes of display hardware is discussed as follows:

5A.1 CONSOLE DISPLAY EQUIPMENT

The devices available to display data on consoles are of seven types (arranged in order of increasing complexity):

a. Lights and lighted signs
b. Meters and clocks
c. Individual character displays
d. Plotters, pointers, and chart recorders
e. Printers and typewriters
f. Cathode ray tubes
g. Complete display image projection systems.

5A.1.1 Lights and Lighted Signs

Because of the simplicity of this type of device, hundreds of varieties exist. It is beyond the scope of this document to list all manufacturers and types. For the IMCC console displays, displays of this type will be used. Selection will be made on the basis of reliability, maintainability, appearance, and cost.

5A.1.2 Meters and Clocks

These devices are also very simple to manufacture with hundreds of models available. Again, a detailed listing of all types will not be made. Considerations for selecting a meter include:

a. Mechanical accuracy of reading

b. Visual accuracy of reading (mirrored scale prevents parallax)

c. Flexibility (ease of changing scale markings)

d. Provisions to remember and display maximum and minimum readings

e. Panel space required.

5A.1.3 Individual Character Displays

The increasing need for accurate display of digital data has led to the development of dozens of devices generally classed as single character "digital readouts." These may be used alone or in arrays to show numbers and alphanumeric text. The basic design is a box which takes digital electrical signals in one face to control the generation of a single symbol or character on the opposite face. To judge such devices, they may be compared with the following description of an "ideal" digital readout:

a. Decoding. The signal levels on "n" binary input lines should control the selection of one out of 2^n possible symbols for display.

b. Storage. After the input signals have been applied, it should be possible to remove them without destroying the display of the selected character.

c. Display. The displayed character should be shaped for easy recognition from any viewing angle under any ambient light condition ranging from bright sunlight to total darkness.

d. Response Time. The time to change to the display of a different symbol after the input is applied should be comparable to the time required by the system to change the input.

e. Module Size. The module box should have a height only slightly higher than the displayed character height, a width only slightly greater than the displayed character width, and have almost no depth.

f. Power. The readout should consume a minimum of power while the displayed character is being changed and consume no power while merely storing and displaying.

Of course, the modules should be inexpensive. None of the modules existing today have all the features at the same time. Many devices disregard the basic functions of decoding and storage to allow an apparent low module price. However, when the necessary external decoding and storage is provided, the actual cost per module is usually several times the apparent cost. Thus, regardless of the widely varying module prices quoted, the complete hardware cost of a single-character digital readout having decoding and storage is close to $100, regardless of implementation or manufacturer.

A representative cross-section of available digital readouts has been classified according to display techniques:

a. Ambient Light Devices. Such devices use reflected room ambient light to display the character. Such devices best satisfy applications requiring easy readability over a wide range of lighting conditions. Table 5A.1.3-1 compares these units.

b. Projection Devices. The end of these units contains a small rear-projection screen upon which a single character (or word) is projected. Some position movable stencils between the screen and the lamp, while others contain a set of fixed stencils or slides each with its own lamp. Table 5A.1.3-2 compares these units.

c. Edge-Lighted Devices. This mechanization uses a stack of transparent plates, each of which can be individually edge lighted. Each plate has its character engraved or etched to throw light forward when the associated edge light is on. Table 5A.1.3-3 compares these units.

d. Lighted Segment Devices. These devices contain a fixed array of lightable segments which may be turned on in various combinations to form approximations to various characters. Table 5A.1.3-4 compares these units.

e. Glow Tube Devices. This category includes a variety of miscellaneous glow tube techniques including selectable character-shaped filaments in a glow tube, stroboscopically-illuminated moving character drums or belts, and neons directly viewed through stencil cut-outs. Table 5A.1.3-5 compares these units.

Table 5A. 1. 3-1

AMBIENT LIGHT DIGITAL READOUTS

Manufacturer	Manufacturer's Designation	Principle of Operation	Character Height	Module Size W	Module Size H	Module Size L	Input Required	Power Required	Change Cycle Time	Maximum Number of Characters	Life	Remarks
Allard Instrument Corporation	Type 201, 202	7 electromagnetically driven segments can each change from black to white	1-1/2"	1-7/16	1-15/16	1-3/4	7 lines (one per segment)	0.4 watts per segment	0.1 sec.	10	----	
	Type 203, 204	14 electromagnetically driven segments can each change from black to white	3"	2-11/16	3-9/16	2-13/32	14 lines (one per segment)			64		
Litton Systems, Inc	Deci-Line	Motor-driven tape advances to show character	1/4"	3 (5 Characters)	5/8	8	4 lines (coded)	----	0.33 sec.	10	----	
Patwin (Magnaline)	Model 36A10	Character Drum Rotated by electromagnets, held by permanent magnet	5/8"	23/32	2-1/2	2-1/2	10 lines (one per character)	1 watt	0.55 sec.	10	10^7 operations	Can be seen in almost any light (bright sun to dim indoors), require power only while changing
Presin Co. (Elmeg Data)	EZ 10/0	Character Drum Rotated by electromagnets	1/5"	2/5	1-1/2	3-4/5	pulse	24V d.c.	0.6 sec.	10	----	
Sigma	9 DEO 1	Character Drum Rotated by Cyclonome motor	1"	1-7/8	1-5/8	5-3/8	4 lines (coded) plus pulse	4 watts	0.5 sec.	10 plus blank	2×10^7 operations	
Teleregister	Type K	Character Drum Rotated by magnetic escapement	15/16"	1-4/9	1-8/10	4-1/2	pulses	50V at 0.66 amp	0.8 sec.	10 plus blank	----	
	Type 68		1/2"	1-1/16	1-1/16	5-3/16	4 lines (coded) plus pulse	50V at 0.4 amp	0.4 sec.			
Union Switch & Signal	---	Motor-driven tape advances to show character	3/8"	11/16	1-5/8	5-1/8	4 lines (coded)	3 watts	3.0 sec.	10	10^6 operations	
	---		9/32"	5/8	1-3/4	11-1/4	6 lines (coded)	7 watts	4.0 sec.	64	10^4 operations	

Table 5A. I. 3-2

PROJECTION DIGITAL READOUTS

Manufacturer	Manufacturer's Designation	Principle of Operation	Character Height	Module Size W	Module Size H	Module Size L	Input Required	Power Required	Change Cycle Time	Maximum Number of Characters	Life	Remarks
Burroughs Corporation	LD - 11	10 bulbs each with a small lens to project a single character "slide"	3/4"	1	1-3/8	3	10 lines (one per bulb	0.8 watts	instant	10 (20 in other model)	lamp life	Short messages can be substituted for individual characters
Data Scope Corporation	SRD - II	Light shines through movable slotted plates	1-4/9"	1	3-1/8	2-1/2	4 lines (coded)	signal: 2.1 watts + 2 bulbs	0.033 sec.	10	----	short depth
Genesys Corporation	CPR - 16	Light shines through 4 movable perforated plates positioned by 4 electro-magnets	1-1/5"	1-1/2	2-1/2	2-4/5	4 lines (coded)	150 Ma. at 12V. + 6 W. bulb	0.1 sec.	16	lamp life	Compact direct binary to decimal
Industrial Electronics Engineers	Series 120000	12 bulbs each with a small lens to project a single character "slide"	5/8"	---	---	---	12 lines (one per bulb)	1.8 watts	instant	12	lamp life	Short messages can be substituted for individual characters
	Series 10000		1"	9/16	2-5/8	5-11/16						
	Series 80000		3-3/8"	3-3/10	5-3/10	5-11/16						
	Bina-View	Light shines through 4 movable perforated plates positioned by 4 electro-magnets	1-3/8"	1-4/5	3-1/4	6-3/4	4 line-pairs (coded) + pulse	signal: 0.16 watts pulse: 2 watts + bulb	0.05 sec.	16 (40 or 64 in other models	----	Power varies with choice of coils and lamps, has memory
Potter Instrument	--	Light shines through electromechanically positioned stencil vane	1/2"	1	3-1/2	9	4 lines (coded)	signal: 2 watts + bulb	0.05 sec.	10	----	4 solenoids select proper vane
Servomechanisms, Incorporated	IL - 2000	Light shines through movable perforated plates positioned by electro-magnets	1/2"	1	1-3/16	4-1/2	6 lines (coded)	pulses: 2 watts + bulb	0.05 sec	64	----	Has memory
Tasker Instruments	Quik - C Model 12-R	12 bulbs each with a small lens to project a single character "slide"	5/8"	3/4	1-1/8	3-3/4	12 lines (one per bulb)	1.8 watts	instant	12	lamp life	Short messages can be substituted for individual characters

Table 5A. 1. 3-3

EDGE-LIGHTED DIGITAL READOUTS

Manufacturer	Manufacturer's Designation	Principle of Operation	Character Height	Module Size W	Module Size H	Module Size L	Input Required	Power Required	Change Cycle Time	Maximum Number of Characters	Life	Remarks
Cubic Corporation	---	Edge-lighted etched plastic plates	--	---	---	---	10 lines (one per bulb)	1.2 watts	0.033 sec.	10	lamp life	
Electro-Instruments	Miniature	Edge-lighted engraved Lucite plates	1/2"	2	1-3/4	1-3/8	10 lines (one per bulb)	1.2 watts	instant	10	lamp life	
	Regular		1"	2	2-7/8	1-3/8						
Kin-Tel	---	Edge-lighted etched plastic plates	--	---	---	---	10 lines (one per bulb)	1.2 watts	instant	10	lamp life	
Milman Engineering Co.	Model R-700	Edge-lighted engraved Lucite plates	1"	1	$2\frac{27}{32}$	---	12 lines (one per bulb)	1.2 watts	instant	12	lamp life	Polaroid filter reduces effect of incident light
Non-Linear Systems	---	Edge-lighted engraved Lucite plates	1"	---	---	1-1/2	12 lines (one per bulb)	1.2 watts	instant	12	lamp life	
			2"	---	---	1-1/2						

Table 5A. 1. 3-4

LIGHTED SEGMENT DIGITAL READOUTS

Manufacturer	Manufacturer's Designation	Principle of Operation	Character Height	Module Size W	Module Size H	Module Size L	Input Required	Power Required	Change Cycle Time	Maximum Number of Characters	Life	Remarks
Beckman/Berkeley	---	7 lightable segments form character	1-1/4"	---	---	---	4 lines (4-2-2-1 code) + pulse	signal: - 20V pulse: 23V	0.077 sec.	10	bulb life	Bright red numerals
Computer Measurements Corporation	Model 160 A	5 x 8 matrix of neon bulbs	2-1/4"	2-1/16	2-11/16	3-3/4	4 lines (coded)	signal: - 25V + 190V ac at 20 Ma.	0.1 sec.	10	neon bulb life	Memory feature available
I. D. E. A.	SGS - 101	7 lightable segments form character	15/16"	1-1/8	2-1/8	3-3/8	7 lines (one per bulb)	1 watt	instant	10	neon bulb or tungsten bulb life	Either neon or tungsten bulbs
	SGS - 401	16 lightable segments for character	1-3/4"	1-1/2	3	10	16 lines (one per bulb)	1.2 watts		36+		
Navigation Computer Corporation	1120 Series	5 x 7 matrix of neon bulbs	4"	3-3/4	5	3-1/2	4 lines (coded) or pulses	2.5 watts	10^{-6} sec.	10	neon bulb life	Counting option available
R. C. A.	EL - 300	7 lightable electro-luminescent segments	1"	1-1/8	1-5/8	3/4	7 lines (one per segment)	270V a.c. at 0.5 Ma.	nearly instant	10	3000 hours	Blue, green, yellow, or white
	ELSI		1-1/2	1-1/2	2	1						
	ELSI		3"	3	4	3/4						
Robotomics Enterprises	Model 1401	7 lightable segments form character	1"	1-7/16	2-1/8	4-1/4	pulse	30V at 150 Ma. + lamp	0.005 sec.	10	neon bulb or tungsten bulb life	Either neon or tungsten bulbs
	Model 2001	16 lightable segments form character	2-3/16"	3-1/2	2-1/2	3-1/4	16 lines (one per segment) + pulse	lamps	instant	36+		
Sylvania (Panelescent)	NU - 150	9 lightable electro-luminescent segments	various sizes (no stock items)				9 lines (one per segment)	A.C.	nearly instant	10	3000 hours	
	AN - 150	14 lightable electro-luminescent segments					14 lines (one per segment)			36+		
Westinghouse (Rayescent)	RN 0500	14 lightable electro-luminescent segments per character	1/2"	2 (3 characters)	1-1/16	3/4	42 lines (one per segment)	260 A.C.	nearly instant	36+	3000 hours	
	RN 0900		9/10"	1-1/8	1-1/2		14 lines (one per segment)					
	RA 1375		1-3/8"	1-1/2	2-1/8							
	RA 2750		2-3/4"	2-3/8	3-7/16							
	RA 4000		4"	3-1/4	4-3/4							

Table 5A. 1. 3-5

MISCELLANEOUS GLOW-TUBE DIGITAL READOUTS

Manufacturer	Manufacturer's Designation	Principle of Operation	Character Height	Module Size W	Module Size H	Module Size L	Input Required	Power Required	Change Cycle Time	Maximum Number of Characters	Life	Remarks
Beckman/Berkeley	---	10 vertically aligned neon bulbs each behind a stencil of a different number	1/4"	1-3/8	5-1/2	5-1/2	pulse	--	0.8×10^{-6} sec.	10	--	counts pulse, preset counting available
Baird Atomic (Digitron)	GR 10G	10 shaped filaments in cold cathode glow tube	1-3/16"	1-3/16	3-1/2	1-3/16	10 lines (one per filament)	220V d.c. at 9 Ma.	nearly instant	10	--	variations available
Burroughs Corp. (Nixie)	Miniature (7009)	10 shaped filaments in cold cathode glow tube	3/10	2/3" round		1	10 lines (one per filament)	170V d.c. 0.4 watts	nearly instant	10	5000 hr.	
	Standard (6844A)		3/5"	1-1/16" round		1-3/8						
	Super (7153)		4/5"	1-1/4" round		1-5/8						
	Jumbo (B 7011)		2-1/4"	3" round		3-3/4						
Computer Measurements	100A, 110A	10 vertically aligned neon bulbs each behind a stencil of a different number	1/4"	1-3/8	5-1/2	5-1/2	pulse	100V peak	0.8×10^{-6} sec.	10	--	counts pulse, preset counting available
Hazeltine	Randid	10 neon bulbs stroboscopically illuminate moving belt (10 simultaneous characters)	1/4"	7-1/2	3-1/2	3-1/2	6 lines (coded)	--	nearly instant	64	--	combined data storage and readout
Kearfott (Digistrobe)	STO-170-B	Pulse neon stroboscopically illuminates drum revolving inside contrarotating slotted cylinder (5 simultaneous characters)	1/4"	1-5/8	7/8	8-1/4	4 lines (coded) per character	20 W	0.056 sec.	10	2000 hr.	6 digit model available
National Union Electric	NUP 102	10 shaped filaments in cold cathode glow tube	1/2"	1-1/4" round		1-3/4	10 lines (one per filament)	150V d c. at 2 Ma.	nearly instant	10		
Navigation Computer Corp.	1123-26, 1121-22	Neon gas tube counting indicator	4-1/2"	3-3/4	5	--	pulse	2.5 W	instant	10		counts

5A.1.4 Plotters, Pointers, and Chart Recorders

Although chart recorders are usually classed as instruments rather than displays, they can be excellent displays for showing a history of analog or rapidly-sampled digital data as a function of time. If time is not one of the variables, or if alphanumeric annotation is desired, their usefulness is limited. Digital X-Y plotters are often used if time is not one of the two variables, since the head can be moved in any direction. Many such plotters also provide a print head containing a limited selection of symbol shapes. The symbol may be changed under digital control between marking points. This allows time-shared plotting of more than one variable or a quantized representation of a third dimension for a single plot. Servo-controlled pointers in conjunction with other displays are very useful in pointing out data remotely. A variation of this by Telautograph and others uses a pen which is slaved to a remote source of data. As the pen at the remote source is used to write, the writing is duplicated by the slave pens.

For the IMCC missions, such devices have adequate resolution and response time to form usable displays. Because of the acoustical noise level or equipment size problems associated with such electromechanical devices, their use will probably be confined to support area personnel. The silent, electronic, multi-purpose displays envisioned for the Mission Operations Control Room will perform the same functions (plotting) and can be time shared for other types of format (test, pictorial, etc.).

5A.1.5 Printers and Typewriters

Since the alphanumeric text format is so valuable for displays, over one hundred devices have been made which mechanically print characters chosen from a stored type font. As opposed to a digital plotter which allows random positioning of a relatively few symbol types, printers and typewriters have a larger selection of character types but usually are restricted to a sequential advance in character positioning. For this discussion, a device which prints one character at a time in a line is a typewriter while a device which prints a line at a time is a printer.

With the exception of a Motorola unit which prints electrically on sensitized paper and equipment using electrostatic printing from cathode-ray tubes (described later), most printers and typewriters produce too much acoustical noise and require too much space for use in the Mission Operations Control Room. They will find applications in the support areas. With moderate difficulty, a printer or typewriter can be programmed to arrange symbols to generate rough approximations to pictures, graphs, and line drawings. This feature will not be used at the IMCC since superior devices will be provided for producing such formats.

5A.1.6 Cathode Ray Tubes

The extremely rapid response time and versatility of cathode-ray tubes have resulted in wide use of these devices for displays. The discussion of this important topic will be in three parts:

a. Characteristics of available cathode-ray tubes
b. Characteristics of available image generators for cathode-ray tubes
c. Characteristics of available television systems.

Twenty-six different special cathode-ray tubes are compared by Table 5A.1.6-1*. Since that table was prepared, other special tubes have appeared. One type uses an array or matrix of fine wires protruding through the glass face of the CRT. Wire spacings as close as 500 per inch can be obtained. Such tubes are used to conduct a charge pattern to paper for high-speed, noiseless printing. The images are developed by the electrostatic attraction of a colored toner to the paper. The toner can be stabilized by heat or other means. Specific brand names of such tubes are Printapix, Videograph, and Raytheon CK 1366-9.

*Table 5A.1.6-1 is reproduced from an article by R. A. Barker, "Techniques of Dynamic Display, Part I: Cathode Ray Tubes," Control Engineering, Vol. 7, No. 2, pp. 100–105, February 1960.

TYPE OF DISPLAY	KEY FEATURES	APPLICATIONS	ADVANTAGES	LIMITATIONS	SUPPLIER
CHARACTER GENERATION TUBES	Identification as well as display of information by this cathode ray tube which can present one or more numeric, alphabetic, or alphanumeric characters at the same time. Generation can be by raster scan, Lissajous, or the shaped beam.				
Charactron	The tube has a 19-in. diagram screen and is used for visual displays. The heart of the tube is the beam-forming matrix; there are 64 characters arranged in an 8 by 8 format. Tube with 17-in. diameter usable face costs about $1,600. (See Figure A)	Can display alphanumeric symbols and analog data concurrently. In most applications a display rate of approximately 10,000 characters per sec is used. Depending upon the system parameters, a rate up to 20,000 characters per sec is attainable.	The choice of characters is essentially unlimited. Only one character is generated at a time. Hence, any character may be positioned at any point on the screen.	At speeds higher than 20,000 characters per sec component limitations destroy the display usefulness.	Stromberg-Carlson Div. General Dynamics (Similar tube made by Machlett Laboratories).
Compositron	Can display several thousand letters per sec.	Characters are displayed in luminous form for photographing. Output device in data processing system.			Radio Corp. of America
Indicoder	Can present 12 characters (numerals zero through nine, plus signal and minus sign). Displays are 1 in. high, discernable at a distance of 20 ft.	Displays a limited number of characters, one character at a time. Converts binary-coded digital words directly into a visual numerical display.	Small size, rectangular face; can be stacked in any desired pattern. Several hundred tubes can be operated in parallel by a common set of high voltage power supplies. No intermediate amplifiers required.	Can present only 12 characters.	Stromberg-Carlson Div. General Dynamics
Typotron	Combines shaped beam technique of charactron tube and storage technique of Memotron (see below). Character height is ⅛ in. Writing speeds are as high as 25,000 characters per sec. Resolution is 200 to 240 lines. (See Figure B)	Can display alphanumeric information at any location on the tube face, retain it indefinitely and erase it at command.			Hughes Aircraft Co. (Similar tube made by Machlett Laboratories).
DIRECT VIEW STORAGE TUBES	Developed to circumvent the unsatisfactory brightness characteristics of long persistence phosphors. Intelligence is deposited on a storage mesh by a "write gun" at relatively slow rates; a "flood gun" provides a continuous stream of low velocity electrons which excite the phosphor stream in the pattern of the charges deposited on the storage mesh.				
RCA 6866	Available with selective erasure. Three to four halftones can be reproduced; resolution is 400 lines at center. (See Figure C)	Developed as a bright indicator for airborne search radar applications. No deterioration in brightness for a period of 10 sec, and a satisfactory display can be maintained for 60 sec after writing has ceased.			Radio Corp. of America
Iatron	Available in two all-magnetic forms, and in an all-electrostatic direct view tube. Electrostatic focusing reduces resolution by 25 percent.	Writing speed between 10,000 and 100,000 centimeters per sec.	Offers controllable persistence (from 1 millisec to several minutes) and at least four discernable levels of brightness for halftones.		Farnsworth Div., IT&T
Tonotron	Available in 3-in. and 5-in.; 10- and 20-in. tubes under development.	Writing speed is 300,000 in. per sec (large sizes are 150,000 and 25,000 in. per sec).			Hughes Aircraft Co.
Memotron	Available in 5-in. tube.	Writing speed is 200,000 in. per sec. Writing speed of 1,000,000 in. per sec possible with special circuitry.	Persistence may last for days.	Cannot display halftones. Image presented must be intentionally erased. Erasure time is from 50 to 200 millisec.	Hughes Aircraft Co.
Dumont K1878	Available in 10-in. tube. Halftones can be reproduced with six levels of output brightness. Resolution is 50 lines per in. minimum.	Writing speed is a minimum of 20,000 in. per sec at maximum beam current.	Minimum storage of 3 min; erase time is 200 to 500 millisec.		Dumont Laboratories

Table . 5A.1.6-1

CATHODE RAY TUBE DYNAMIC DISPLAY TECHNIQUES

TYPE OF DISPLAY	KEY FEATURES	APPLICATIONS	ADVANTAGES	LIMITATIONS	SUPPLIER
SCAN CONVERSION TUBES	Nonviewing CRT into which video information can be stored at one rate and by one scanning method and from which the stored video can be extracted at a different rate and by a different scanning method. Raw radar data, for example, can be inserted, stored, and extracted for display on a standard CRT at rates that circumvent the undesirable brightness and persistence characteristics of long persistence phosphors. The resulting display can be flicker-free, bright, and viewed under higher light levels than a standard radar display.				
Intec Video Transformation Tube TMA 403X	Double ended tube with magnetic deflection and electrostatic focusing on the write gun and electrostatic focusing and deflection on the read gun. Costs about $2,600. (See Figure D)	The definition of 1,000 TV lines is derived. Storage is adjustable from 0.1 sec to 20 min plus. It is possible to read the output signal on the order of 150 to 20,000 scans before erasure of the written information. The signal-to-noise ratio is 30 to 1.	Does not require RF modulation to sort the write and read signal. The tube is capable of halftone rendition. The tube shows 8 to 10 steps of gray in written information.		Intercontinental Electronics Corp.
Graphechon	Double ended, nonviewing, electrostatic charge storage tube. Costs about $1,100.	Used with scan conversion equipment, writing and reading can be conducted at the same time.	Can supply as many as 6,000 copies of stored information with a signal-to-noise ratio of 10 to 1.	Can produce only crude halftones. Requires some method of separating reading and writing signals, usually rf modulation or time-sharing.	Radio Corp. of America
Radechon	Single ended, nonviewing barrier-grid charges storage tube. (See Figure E)	Can store information received in analog or digital form.	Storage time is controllable from microsec to minutes. Information can be read out a number of times.	Must be time-shared for reading and writing.	Radio Corp. of America (Similar tube made by Farnsworth Div., IT&T).
Day Tube	Double ended storage tube. Uses three guns, electrostatic write and erase guns, and a magnetic read gun.		Storage time is several minutes.	Is still developmental.	General Electric Co.
Recording storage tube	Nonviewing device.	For scan conversion, indefinite image storage, slowed down video. Resolution is about 400 lines at 50 percent modulation level.	Signal can be stored for hours. Single image can be read out 20,000 to 30,000 times.	Time must be shared among four modes.	Raytheon
COLOR TUBES	Can be programmed to display different variations at the same time. Major differences between tubes below stem from their means of obtaining color: stimulating different colors with separate guns or masking the phosphors.				
Chromatron	Two- and three-color tubes available. Phosphors are laid down in thin parallel strips of alternating colors. Two sets of grids direct electrons to the proper color. (See Figure F)		Brighter and more efficient than shadow mask color tube (below). No convergence or misregistration problems. Not affected by the earth's magnetic field. Uses essentially same deflection voltages as standard CRT's.	Requires elaborate power supply.	Litton Industries
Shadow mask tube	Uses three guns spaced 120 deg apart and view plate on which are deposited three phosphor dots of different colors (red, green, and blue) in a triangle. Shadow masks are placed between gun and dots so that each gun can hit only one color dot.			Sensitive to slight variations in the earth's magnetic field. Protection must be provided against X-radiation. Brightness is limited. Color purity is hard to obtain.	Radio Corp. of America
Color Storage Tube	Combines features of Tonotron with shadow mask tube.	Can write at speeds up to 300,000 in. per sec.	Capable of halftone presentation. Resolution is 30 to 35 lines per in.	Display area limited (doubtful if 20-in. tube can be built). Still in development stage.	Hughes Aircraft Co.
Prismachrome (Gear Tube)	Three colored phosphors are geometrically oriented so that each gun illuminates only the desired phosphor.		Extremely rugged, cannot lose its registration alignment due to shock or vibration. High level of brightness is obtainable.	Tube is bulky for its screen size. Delivery time could be as long as 24 months.	Hoffman Electronics Corp.
Penetron	Color CRT with thin color phosphors deposited in layers on the tube face. The tube has one electron gun; color selection is achieved by varying the accelerating potentials. Difference for successive layers is on the order of 3 to 4 kv.	May be able to pass from one primary color through all the intermediate hues to the next primary color by appropriately adjusting the accelerating voltage.	Simpler and more rugged than shadow mask tube or Chromatron.	Only two color tubes have been built. Still in development stage.	General Electric Co.

Table 5A.1-1 (Contd)

Apple Tube	Color TV system using a beam indexing tube. Three primary color phosphors are deposited in narrow vertical strips on the tube face with an additional strip used for locating the writing beam. An electron gun generates two beams, one for writing and one for developing an indexing signal. As the two beams scan horizontally, the indexing beam generates a signal which synchronizes the intensification of the writing beam with the dot-sequential type of color signals	Compatible color TV system.	Said to be more efficient than shadow tube and has no convergence problem because it does not use masks or grids.	Requires many circuit adjustments.	Philco Corp.
SPECIAL TUBES	Radically different developments using cathode ray tube techniques that do not fit into any of the above groups. Advantages include brighter, sharper focusing in smaller space; high resolution; sharp display.				
Skiatron	A dark trace tube; therefore coating absorbs light when bombarded with electrons.	Available with a refractive optical projection system that can throw a 10-ft diameter picture. Writing speed is sufficient for producing raw radar data. Resolution of projected display is 1,100 lines.	Projected displays are clear and sharp. Although ambient lighting can deteriorate projected display, local illumination for reading and writing will not affect the display if rays are prevented from striking the screen.	Requires time to build up to full contrast and time to decay after excitation is removed. Tube may be erased in 2 sec, but an additional 5 sec must elapse before rewriting can take place. To date limited to black trace on a bright background.	Skiatron Electronics and Television Corp.
Aiken Tube	Flat cathode ray tube. (See Figure G)	Linearity accuracy is 5 percent. Resolution is as high as 400 lines. Modifications under development: a) Two-color Aiken tube — glass plate with different colored phosphors is inserted between face plate and back plate of a standard Aiken tube. Uses a separate electron gun for each color. b) Three dimensional Aiken tube. Cube-shaped tube contains horizontal glass layers, each coated with a transparent phosphor. Each layer has an electronic gun. No goggles or viewing equipment required but third dimension presentation is discrete rather than continuous. c) Flat polar-coordinate CRT. d) Charactron flat tube — normal electron gun is replaced by Charactron components.	Three times the brightness of a conventional CRT, and 20 times the focusing power. 21-in. tube requires only 20 percent of power needed by conventional CRT. Potentially can be built in large sizes, up to 5 by 5 ft.	Delivery of 20-in. tube is 6 months. Large tubes have not actually been built.	Kaiser Aircraft and Electronics Corp.
Light Valve Tube	Scanning electron beam deposits charges on a special semiconductor screen which changes from opaque to transparent in accordance with pattern of stored charges. A lamp behind the screen shines through the pattern projecting it like the light of a slide. (See Figure H)		Bright display because of separation of projection light source and pattern generating functions.	Requires an additional year of development work for production.	Resdel Engineering Corp
Large Cathode Ray Tube (30-in.)	Will operate with 30,000 volts accelerating voltage, magnetic deflection.	Tube has a curved face but is equipped with a plotting overlay to reduce parallax. Being built as a plan position indicator display.	Large display tube. Potentially high resolution, up to 1,000 lines.	High cost: $30,000. High voltage is hazard for operator. Brightness cannot compare to optical projection systems.	Polarad Electronics Corp.
Moving Target Indicator INTEC TCM-13X	Barrier-grid storage tube. A high definition triode gun with simultaneous read and write. Electrostatic focus and deflection; 15 shades of gray. Resolution of 400 TV lines is derived as measured by orthogonal write and read technique and with a 50 percent output signal modulation.	In moving target indicator techniques the tube provides an elimination ratio of 20.	Speed velocity of 0.6 mm per microsec. Signals can be added and integrated.		Intercontinental Electronics Corp
INTEC TCM-154	Barrier-grid storage tube. A high definition triode gun with electrostatic focus and deflection and astigmatism correction lens. Definition: at 50 percent modulated output signal, the tube has about 700 TV lines.	Originally developed for electron switching in telephone circuits.	Erasure with television or similar-type raster; signals are stored and then read at a later time.		Intercontinental Electronics Corp.

Table 5A 1 6-1 (Contd)

A storage tube now under development by the Hughes Aircraft Co. allows selective erasure of the stored image or simultaneous display of stored and non-stored images by control of accelerating potentials.

Several new tubes are under development (Litton, others) which combine a bright phosphor high in ultraviolet output with a fiber optic faceplate to conduct the bright image to the face of the tube. The object is to contact print on Kalvar film to get slides for projection. Such tubes are still developmental. The main problem is that the high beam energies required break the vacuum seal of the fiber optic bundle causing destructive leaks. Kalvar is discussed under projection displays.

Many extra-bright cathode ray tubes are becoming available which permit direct projection of the CRT image onto a larger screen at adequate brightness levels. This is discussed under projection displays.

The desirability of superimposing dynamic cathode ray tube displays on projected-background reference slides has prompted the limited use of optical ports in CRT's. An optical-quality flat window in the rear of the tube envelope allows images from film slides to be rear-projected using the CRT phosphor as a screen. A 17" DuMont tube is so used in a Thompson-Ramo-Wooldridge console. Smaller tubes are also available with one or two optical ports.

5A.1.6.1 Image Generation for Cathode Ray Tubes

The method of generating images on a cathode ray tube is governed by many factors. Some of the most important considerations are:

a. Whether the image source is pictorial (actual scenes, slides, movies, etc.) or whether it is computer-generated digital data

b. The format if the display has a non-pictorial source:
   1. Alphanumeric characters and symbols
   2. Line drawings
   3. A combination of line drawings and symbols.

c. The rate at which the display must be driven

d. The amount of data displayed

e. The characteristics of the driving system (computer, tape, scanner, etc.).

In general, pictorial-source displays are put on cathode ray tubes using television techniques. These are discussed later.

Line Drawings: A computer driving a cathode-ray tube in a line drawing mode uses one of two basic approaches.

a. Continuous Line. The computer sends out successive digital coordinates representing points on the line to be drawn. These digital coordinates are changed to beam deflection signals by digital-to-analog converters. As the beam moves from coordinate to coordinate, special hardware is provided to make the movement linear. Gaps in the line are provided by blanking the beam during a movement.

b. Vectoring. If continuous-line drawing capability is not provided, a display system which generates discrete symbols only can array symbols in an approximation of a continuous line.

Symbols: A computer driving a cathode ray tube in a symbol drawing mode uses one of two basic approaches.

a. Continuous Line. If the display driving system can generate line drawings as described above, symbol shapes can be programmed into the computer. The successive coordinates from the computer steer the cathode ray tube beam to draw out symbols much as a person would draw them with a pencil.

b. Special Symbol Generation Equipment. As described in other portions of this discussion, an electron beam may be directed against a phosphor for direct viewing, scan conversion for television or photography, xerography, or projection. The beam may be directed against a schlieren or a thermoplastic medium, or the beam may be directed against an array of fine wires passing through the tube face for electrostatic printing. Since so many applications exist, and since speed of beam-deflection requirements exceed that possible using the "continuous line" mode described above, a wide variety of symbol generators for deflecting electron beams has been developed. As shown in Table 5A.1.6.1-1, there are four basic methods of forming symbols. Each is summarized briefly below:

   1. Dot Pattern. Symbol generators of this type provide a coordinate for each dot position of each character. Because of the large amount of storage required, this is expensive if the storage is digital. Often the positioning of dots is limited to a 5 x 7 fixed matrix for each character. If storage is analog, the coordinates are not limited to a fixed array and fewer dots are required for the same

Table 5A. 1. 6. 1-1

SYMBOL GENERATOR TECHNIQUES

Method Of Forming Symbol	Method Of Storing Symbol Data	Resulting Signals	Method of Changing Symbols
Dot Pattern	Logic Circuits	Pulses On Wires	Replace Circuits
	Drum, Cores, Or Computer Memory	Digital Dot Coordinates	Rewrite Digital Memory
	Resistor Net Plus Logic	Analog Dot	Replace Resistor Cards
Scanning	Specially Wired Core Planes	Binary Raster	Replace Core Planes
	Drum Plus Logic	Binary Raster	Rewrite Digital Memory
	Image Mask	Binary Raster	Replace Mask
Wave Forms or Strokes	Sinusoidal Generators Plus Logic	Video x,y,z	Replace Circuits
	Linear Generators Plus Logic	Video x,y,z	Replace Circuits
	Resistors, Transformers	Analog End Point Coordinates	Replace Circuits
	Drum Or Cores	Digital End Point Coordinates	Rewrite Digital Memory
	Image Mask	Video x,y,z	Replace Mask
Beam Shaping	Image Mask	Shaped Beam	Replace Tube

symbol quality. Figure 5A.1.6.1-1A shows a typical implementation of this type with the analog coordinates stored as resistor values. Logical switching selects the set of resistors representing the chosen character and scans it sequentially to obtain a sequence of X and Y analog deflection signals for the cathode-ray tube. The best available equipment of this general type is the one manufactured by Transdata of El Cajon, California. It produces 64 symbol types at 100,000 symbols per second for approximately $6000. Figure 5A.1.6.1-1B shows a digital storage of dot blanking information with a core for matrix beam position.

2. Scanning. Symbol generators of this type develop a full or partial raster for the electron beam and form the character by intensity modulation of the beam in a manner similar to television. Figure 5A.1.6.1-1C shows the formation of a raster scan character with the beam blanking information again stored digitally in cores. In this case, the cores are preset by the character selection winding and are scanned in synchronism with the CRT raster. The first core having an output unblanks the scanning beam. The beam remains on until another core has an output. Thus, the end-points of a series of horizontal lines are specified by the way the cores are laced. The best equipment of this type (C. B. S. Vidiac) is twice as expensive as those using analog-symbol shape storage and is no better or faster. Figure 5A.1.6.1-1D shows analog storage of symbol shape. The scan generator simultaneously generates synchronized rasters on the "flying spot scanner" tube and the output tube. The symbol identification input positions the raster on the scanner tube behind a mask cut out to form the desired character shape. The symbol position input positions the raster on the output tube to the place the output symbol is to appear. As the beam sweeps across the scanner tube, the light output of that tube is monitored by a photomultiplier which blanks the raster on the output tube whenever the scanning spot is behind the mask. A similar technique known as "monoscope" places the mask inside the scanning CRT and generates unblanking signals by detecting secondary emission when the electron beam hits the mask and detecting lack of secondary emission when the beam goes through an aperture in the mask. Still another similar technique uses a separate small scanner tube for each symbol type. The best equipment of this type is currently manufactured by A. B. Dick Co. or the Electrada Corp. and costs about $6000 for 64 symbol types.

3. Strokes. If the dot pattern generators are of the type that sequence through the dots in a manner similar to the "line drawing" mode of symbol generation, the beam can be left

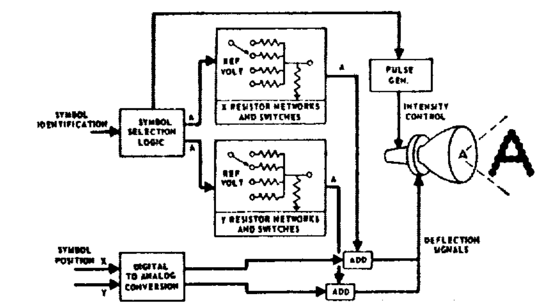


Figure A Dot Pattern Symbol Generation With Resistor Storage

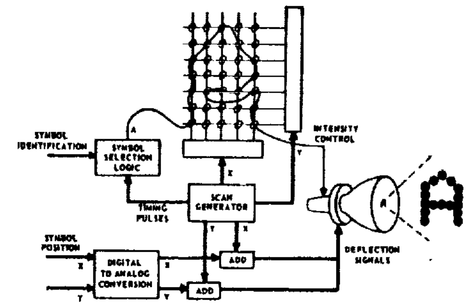


Figure B Dot Pattern Symbol Generation Using Scanning Beam and Core Storage

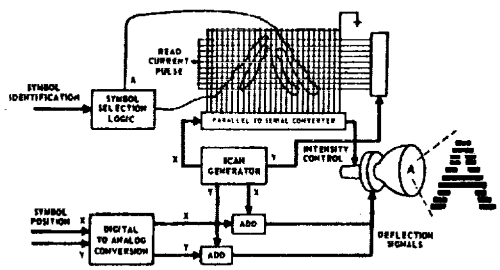


Figure C Scanning Symbol Generator With Core Storage

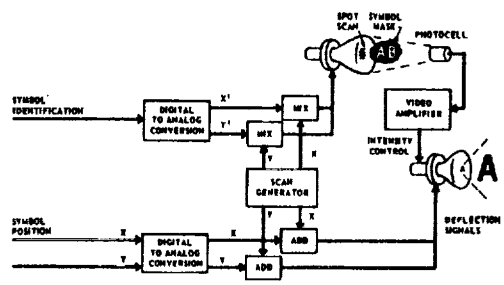


Figure D CRT Mask Symbol Generation

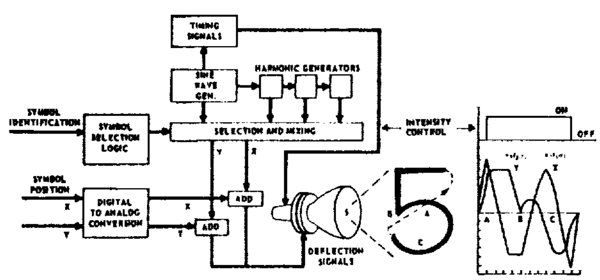


Figure E Symbol Generation by Analog Waveforms

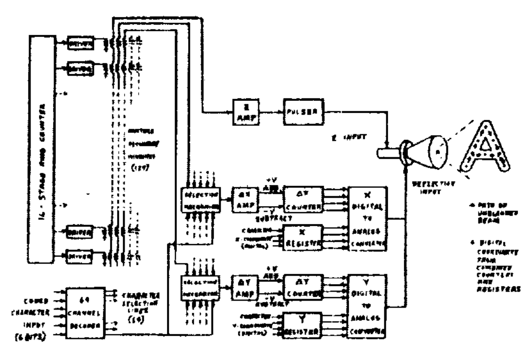


Figure F Transformer, Logic Line Segment Symbol Generation

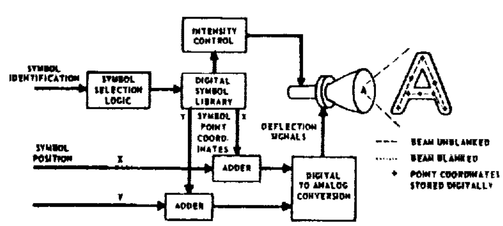


Figure G Line Segment End Point Symbol Generation

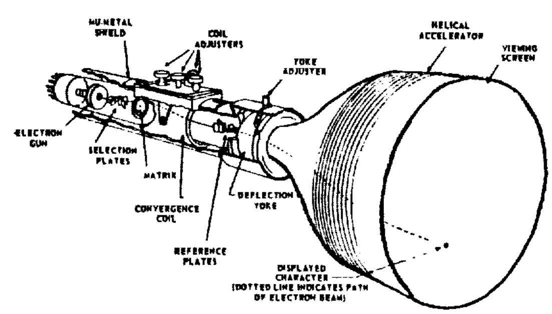


Figure H CHARACTRON Shaped Beam Tube

Figure 5A. 1. 6. 1-1 Special Symbol Generation Techniques unblanked between dots to form a series of strokes. This allows better looking characters or fewer coordinates (dots) to be stored. A good unit of this type now available is made by Strand Engineering Co. of Ann Arbor, Michigan. It produces 64 different 20-stroke symbols at 140,000 symbols per second for approximately $6000. For slow, inexpensive applications where fewer, poorly formed characters are accepted,a selection of a combination of a few fixed strokes out of a set of 8 or 16 is used. Skiatron and R. M. S. Associates produce equipment of this type for about $3000, not including decoding. Figure 5A.1.6.1-1E shows the expensive extreme; very well shaped characters formed as lissajous patterns driven by harmonic generators. A technique to simplify coordinate storage is illustrated by Figure 5A.1.6.1-1F. As the storage elements are scanned, registers holding X and Y coordinates are pulsed to count up, pulsed to count down, or left unchanged. In the Figure 5A.1.6.1-1F which shows an Indian (Tata Institute, Bombay) mechanization, the pulses are stored as transformer secondary windings. In American versions, cores or diodes are used. One American version is made by Marquardt of Pomona, California. Figure 5A.1.6.1-1G represents digital storage of complete coordinates. The symbol identification input causes a "table look-up" in the digital symbol coordinate set storage library and causes the set of beam deflection coordinates to be read out. This technique is going out of use.

4. Shaped Beam. Figure 5A.1.6.1-1H and Table 5A.1.6.1-1 describe examples of a "shaped beam" tube such as the Stromberg-Carlson Charactron. A mask built into the tube itself contains apertures shaped like symbols. While this approach appears very simple, drawbacks are so severe that most newer systems use conventional CRTs together with one of the previously-mentioned symbol generators. Drawbacks of the Charactron and Hughes Typotron include high cost of the tube, complex external control circuits, near impossibility of changing symbol shapes, and extreme physical length of the tube relative to screen size.

5A.1.6.2 Television

If the original image source to be displayed is pictorial, it is most economic to distribute and display such images by means of television. A very large amount of work has produced low-cost, high-resolution TV cameras for televising actual scenes and flying spot scanners for televising slides. If all images must be formed from computer-generated data, the choice between a directly generated and a television display is more difficult.

Any of the CRT image generation techniques described above can be used to drive one of the scan conversion tubes of Table 5A.1.6.1-1. The output of the scan conversion tube can be a high resolution (over 900 line) television signal. In this way, use of television adds extra equipment. Benefits which accrue from using television are that, for large numbers of consoles, inexpensive TV monitors of high quality can be obtained. This saving can be significant compared with non-television CRT consoles. A typical non-TV CRT console (CRT with symbol generator refreshed from magnetic drum) costs approximately $50,000 while a high quality TV monitor can be obtained for approximately $250. Reasonably inexpensive switching and mixing equipment permits using the same TV monitor to view combinations of computer generated outputs from scan conversion tubes and pictorial data from TV cameras and scanners.

In the case of consoles, the use of projection CRTs provides:

a. An inexpensive way to obtain color-coded displays
b. A flat viewing surface which may also be a work surface
c. Increased contrast through directional screens
d. Optical mixing with projected film images.

To get color, a separate projection tube is required for each color channel. Each projection TV tube produces a white on black image. The color is provided by a color filter in each optical path. Thus, images can be shared between black and white and color displays, and colors can be changed by changing filters. If three channels are used to image displays of three primary colors on the same console rear projection screen, careful registration and programming of the data can produce 7 distinct usable colors by optical mixing on the screen. This latter technique seems too complex for the IMCC, but the use of three colors provided by three small CRTs rear-projected on a console screen may be required by the more complex IMCC consoles. On consoles containing only one color per screen, the reduced cost of direct view TV monitor may override the flat screen and better contrast provided by projection TV.

Optical mixing with projected film background or reference images on the console screen implies film equipment at each console. This is justified only if full color or high resolution film displays are required. If the TV system has enough resolution to carry the reference information, film equipment can be centralized. In the latter case, a flying spot scanner would convert the film image to television and electronic video mixing would produce the composite display. The reference background resolution requirements and the anticipated very large number of reference slides indicate that a central slide storage is the best solution for the IMCC.

Compatibility between console displays and large group displays is a big advantage. Projection of CRT data on large screens has extremely low brightness unless the scanning properties of television are used. Large screen projection TV is discussed later.

5A.1.7 Projection Displays for Consoles

Non-television projection displays are used where the simpler techniques previously described provide inadequate color or resolution. The primary application in consoles is the display of one of a fixed set of background, index, or reference slides. Non-television dynamic projection displays have widest application as large-screen group displays. Thus, they are described under that topic, although most group projection techniques can be scaled down to console size with proper optical redesign.

5A.2 THREE-DIMENSIONAL DISPLAYS

A special class of displays which must be discussed separately from the two-dimensional console and group displays is the three-dimensional class. Implementations of such displays are of two types: virtual and real.

5A.2.1 Virtual 3-D Displays

These displays depend upon presenting two slightly different two-dimensional displays. Various techniques are used to make sure that each of the viewer's eyes gets a different image. The viewer's brain is relied upon to correlate the different images into a single three-dimensional image. The ability to perform the correlation and the utility of the resulting image varies greatly depending on the user. Popular methods of providing separate two-dimensional images for each eye include:

a. Complementary Colors. The two images, one in a color complementary to the other (such as one red image and one green image) are projected as a composite on the same screen. The observer wears glasses having one lens one of the colors and the other lens the other color. Rear or front projection is possible, but colored displays are impossible.

b. Polarized Light. The two images each projected with polarized light have their planes of polarization at right angles. The composite picture on the screen is discriminated by having the observer wear polarizing glasses having one lens polarizing in the plane of one image and the other lens polarizing in the 90-degree plane. Since the screen must maintain polarization, rear projection is impossible. Colored displays are possible.

c. Raster Screen. The two images can be sliced into vertical strips and projected as alternating bands of image. A grid of rods in front of the screen, prisms in front of the screen, or directional slat screens, direct all the slices of one image to one eye while blocking the view of those slices for the other eye. In a similar manner, the second eye gets only slices of its image. The observer needs no special glasses but is tied to a laterally fixed viewing position. Screen resolution is reduced. Colored displays are possible.

d. Mirrors. Two physically separate, slightly different images, produced by any of the display techniques described in this report are positioned so that one eye sees one image in a mirror and the other eye sees the other image directly or in a second mirror. Color or any other display technique may be used, but the observer's position is fixed. A prism or lens may be used to perform the same function as the mirror.

e. Partition. Two physically separate slightly different images are positioned side by side. A partition from the boundary between the two images to the observer's nose permits each eye to see only one picture. This is practical only if the images are physically small (slides, small pictures, one- or two-inch cathode ray tubes, etc.). Color is possible and the observer may move his viewer with him if it is small enough.

5A.2.2 Real 3-D Displays

These displays are physically three-dimensional. Dynamic real displays are not well developed. What is available can be classified into two types.

a. Mechanical Three-Dimensional Plotters. These devices use servo-mechanism to position an indicator according to scales on three axes. The problem is in recording the history of successive positioning movements. One implementation by Chrysler has an indicator which is a source of ink. The ink source is moved three-dimensionally through a block of transparent gelatin. The mechanical linkages of the ink source to the positioning mechanism cut the gelatin but the cut "heals" after the linkage moves on, leaving only the three-dimensional ink trace visible in the gelatin block. This device is slow, bulky, heavy, and allows display of a single track only.

b. Layered Two-Dimensional Displays. A layered stack of transparent two-dimensional displays is operated so that each layer shows the function of two dependent variables for a fixed value of the independent third variable. One version is the proposed use of a stack of Aiken flat cathode-ray tubes which are transparent front and rear except where the beam strikes the normally transparent phosphor. Another version by ITT achieves a layered effect by using a single screen. The screen plane is rapidly moved. At each of a programmed set of screen positions, a projection cathode-ray tube is used to form the image for that layer. By repeating the sequence more rapidly than the eye can follow, the effect of a solid display is possible. Another similar implementation would place the moving screen inside the CRT.

The three-dimensional displays which give promise of being available during the IMCC construction time period do not appear valuable in aiding decision-making by IMCC personnel.

5A.3 GROUP DISPLAYS

The problem of scaling-up the size of dynamic console displays to the size required for simultaneous viewing by large groups has kept the number of dynamic large-screen displays relatively low. Physical scaling-up often leads to intolerable bulk, weight, and power consumption. Optical scaling-up proportionally reduces image brightness.

Since giant magnification lenses would be too expensive, optical scaling-up is done by projection onto a large screen. Thus, in this report, group displays are classified either as projection displays or as physically large displays.

5A.3.1 Projection Displays

Cathode Ray Tubes: The ease of rapidly deflecting and modulating a cathode ray tube beam by a computer or by television techniques (both previously described) has made the cathode ray tube a favorite for console displays. Several approaches to projection group displays have been based on attempts to retain those advantages by using a cathode ray tube to form a small image which is eventually transferred to a large screen. Improving this image transfer is one of the most actively pursued goals of the display equipment industry. Ways of transferring include:

a. Directly projecting the cathode ray tube image from the phosphor onto the large screen

b. Photographing the cathode ray tube image from the phosphor, processing the film, and projecting the film image

c. Projecting the cathode ray tube image from the phosphor onto a precharged photoconductor to form an electrostatic image, developing a real image, and projecting it

d. Using a "scotophor" instead of a phosphor on the cathode ray tube and using opaque projection techniques to place the image on the screen

e. Using a thin semiconductor instead of a phosphor to make a "slide" out of the front of the tube for projection using a separate light source entering the rear of the cathode ray tube

f. Using a matrix of fine wires to conduct the electron beam energy through the faceplate to produce an electrostatic image outside the tube, developing a real image, and projecting it

g. Using the electron beam energy to deform a medium inside the tube which can be projected using schlieren optics and a separate light source entering the rear of the cathode ray tube.

5A.3.1.1 Direct Cathode Ray Tube Projection

The use of special tube configurations, high acceleration voltages, and forced-air faceplate cooling allows generation of CRT images which are many times brighter than those normally seen. The number of lumens toward the screen is not much more than 300. Thus, direct projection is limited in use to small screens or to large screens in dark rooms such as occasional closed-circuit television projections in movie theaters.

5A.3.1.2 Photography of the Phosphor Image

To increase image brightness, the CRT phosphor is often photographed to make a slide for projection using a high-intensity light source. Conventional silver halide film is very sensitive to phosphor-emitted light and can be exposed in a fraction of a second. Rapid film processing techniques require about five seconds to develop the film. A process developed by Aeronutronic,which develops in a small "capillary chamber", has no fumes and uses a very small amount of chemicals. Since the CRT image is a bright-line image, the silver-halide image is dark-line after initial development. This is undesirable, since most implementations use the black and white film slides with colored light beams to produce a composite multi-colored display on the screen. Work has been done to chemically reverse the image on the silver halide film. This has been successfully demonstrated in the laboratory, but the processing time takes an additional five seconds.

To obtain the desired positive image slide, another step is usually taken. Since the image is on film instead of a CRT, a Kalvar film is used to speed up the second step. Kalvar uses a dry diazo emulsion on a transparent film base. Exposure to a very intense ultraviolet light creates a latent image of pressure centers in the emulsion. When heated above 212°F, the emulsion softens and the pressure centers expand into small gas pockets of several micron diameter. These small bubbles cause refraction and scattering of light in the exposed areas. The projector must use a lens system which intercepts very little of the scattered light. By proper design, contrast of 200 to one can be obtained and formation of additional gas bubbles while the film is in the projector can be eliminated. The big advantage of Kalvar film is that, if a high-intensity ultraviolet source is available, exposure can be accomplished in 1/2 second. The first operational version of the CRT — to silver halide — to Kalvar technique is made by Aeronutronic Division, Ford Motor Company. Others are being developed by ITT Federal and Kelvin-Hughes.

The rapid heat development feature has led to much effort in trying to expose Kalvar directly from CRT phosphor. Current areas of experimentation use ultraviolet-rich P16 phosphor on a CRT having a fiber optic faceplate to direct more energy to the film. Results appear discouraging because Kalvar is so insensitive, the high beam energies break the vacuum seal of the fiber optic bundle (destroying the tube), and a less desirable dark line image would result on the Kalvar if the other problems could be solved.

5A.3.1.3 Photoconductor Methods

When the CRT image is focused on a precharged photoconducting surface, the charges in the exposed area are conducted away, leaving a static charge only in the exposed areas. The two most advanced versions of this technique are as follows:

The Haloid-Xerox process uses vitreous selenium as the photoconductor. Vitreous selenium has one large problem: it suffers irreversible damage when subjected to temperatures greater than 125°F. If heat can be controlled, it has advantages over other photoconductors. It is more sensitive to light and it is a shiny metal. When the image is developed by cascading charged dark powder on the selenium, the shiny image is used as a reflector in the projection system called Proxi. This technique was chosen to implement the Air Force 465L system, but was abandoned in favor of a CRT — to silver halide — to Kalvar approach.

The RCA Electrofax process uses zinc oxide as the photoconductor. Zinc oxide, while less sensitive and non-reflecting, is stable and can be applied to a film base. Both techniques have a good resolution and contrast with developing in 1/2 second to 2 seconds. Developing is described in slightly more detail under "Wire Matrix-Faceplate" below.

5A.3.1.4 Scotophors

A group of chemicals called scotophors are available. Unlike phosphors which emit light when excited by an electron beam, scotophors become light-absorbing. The result is a dark trace on a light-colored CRT faceplate. This image may be projected by reflecting light off the tube face. Changing images is accomplished by heating the image for several seconds. This erasure problem limits the use of such an approach. Skiatron is the source of most dark trace tube effort.

5A.3.1.5 Semiconductor Cathode-Ray Tube Faceplate

Experimental work in several laboratories is directed toward coating a thin film of semiconductor material in place of cathode-ray tube phosphor. Where charged by the electron beam, the semiconductor becomes transparent. It may then be used as a bright-line slide for light projected through a window in the tube. This technique is not far enough along for IMCC use.

5A.3.1.6 Wire Matrix Faceplate

The Printipix, Sympix Videograph, and Raytheon CK1366-9 allow the charge pattern produced by an electron beam to be conducted through the glass faceplate and applied directly to a non-conducting medium touching the ends of the wire matrix. The latent charge pattern may be transferred to another medium or developed directly by bringing a charged powder into contact with the charge pattern. The powder adheres to oppositely charged areas forming a visual image. The powder may be brought into contact with the charged surface by means of a brush, powder cloud, cascade, or liquid suspension. The powder may be transferred to another medium, erased off to permit medium re-use, or permanently fixed by heat, pressure, or an adhesive. For projection displays, the wire matrices provide resolution inferior to other techniques.

5A.3.1.7 Schlieren Deformation by the Cathode Ray Tube Beam

If the faceplate phosphor is replaced by oil or a thermoplastic, the charge pattern formed is a latent image of the beam's path. Electrostatic attraction will deform the oil immediately and together with subsequent heating will deform the thermoplastic according to the charge pattern. In the case of the oil, the viscosity of the oil film provides storage similar to that of long persistence CRT phosphors. The decay of the deformation requires that the image be continuously regenerated by the electron beam. It also allows the display of rapidly changing information using television techniques. The thermoplastic material, if cooled while the deformation exists, retains the image until the plastic is reheated.

The image is not easily projected. A Schlieren projection system is used which starts with a high-intensity light source outside the cathode ray tube. The light beam is converted to a cross-section of alternating dark and light bands before entering the tube by being reflected off a slotted mirror. If no deformation of the oil exists, the bright bands pass through the tube and fall against a complementary slotted mask which prevents all light from reaching the screen. Light passing through deformations in the oil are deflected to pass between the bars of the slotted mask where they are collected by a lens system and focused on the screen. Since the oil is inside the tube, attempts to increase light output by getting larger deformations can cause oil to reach the cathode, ruining it. These systems have changeable electron guns.

The best available now are the G. E. "Light Valve" and the Swiss "Eidophor" (available in U. S. A. also from Hazeltine or General Precision). The Eidophor is the superior mechanism and has a light output of 3100 lumens compared to 1400 for the G. E. device. Resolution is about 900 lines, and price is about $50,000 per unit. It seems highly likely that large-screen television will be provided in the IMCC using an Eidophor or a Light Valve.

Scribed Plates: These display systems utilize another method of recording images for projection. Electrical signals (representing successive positions along lines used to draw the image) simultaneously operate X and Y coordinate servomechanisms. These mechanisms drive a stylus which scribes a clear line on an opaque glass slide. The stylus is moved by a transparent linkage and is operated while the slide is being shown with an otherwise conventional projector. In a typical implementation, several such projectors are imaged on the same screen, each having a different colored filter in the light path. The colored bright lines are superimposed on the screen along with background data from a film projector. In this configuration, it competes directly and produces displays similar to those produced by the CTR — silver halide — to Kalvar processes. The basic difference is in application. The film systems can produce an entire screen full of detailed line and alphanumeric data in ten seconds. Corresponding data on a plate scriber would take five minutes. The slowness of the scribers is compensated by the ability to watch the slides being drawn and the ability to add to slides at a later time without making a new slide as in the case of later reports on an aircraft or satellite track.

The first such equipment was the Fenske, Fedrick, and Miller Iconorama. A later version by Kollsman Instrument is of much higher quality. It provides twenty automatically changeable slides, automatic projector-bulb changing and automatic selection of one out of eight color filters. Brightness is not exceptional with 1000 lumens available toward the screen. It is probable that a set of such projectors will be required at the IMCC.

Photochromic: A group of photochromic dyes have been developed by the National Cash Register Company. Normally transparent, these dyes become temporarily opaque when exposed to an intense ultraviolet light. After a few minutes exposure to white projection light, they return to the clear state and may be re-used. Control of the writing is similar to that for scribed plates except that the servomechanisms move mirrors instead of scribers. The mirrors are used to deflect a pencil beam of intense ultraviolet light for writing on a sheet of film containing photochromic material. The sheet is used as a slide in an otherwise conventional projector and may be drawn on while the slide is in view. To speed the drawing of symbols, a second light beam is extruded through a symbol mask by another set of controlled mirrors. Disadvantages include the fact that a large-scale version has not been built, the traces fade quickly in the projector, and the images are dark line. This latter drawback makes color coding of traces on different slides almost impossible and requires that all superimposed slides including the reference background be shown by the same projector. For the IMCC, the photochromic approach does not appear nearly so promising as the bright line scriber or film approaches.

Mechanical Scan Television: Another type of display system under study uses a rotating mirror to convert a bright pencil beam of light into a television raster. To get a television picture, the light beam must be modulated by the electronic television video signal. This is very difficult since the beam modulator must change from opaque to clear at multimegacycle rates. Two approaches appear promising:

A device known as the Kerr Cell contains an electrolytic medium which can rotate the plane of polarization of light passing through the cell according to an external voltage applied to the cell. Light from a high-intensity source is polarized before being sent into the Kerr Cell. If the Kerr cell does not rotate the plane of polarization, the light is stopped after leaving the cell by a polarizing filter at right angles to the plane of the beam. Applying voltage to the Kerr cell rotates the plane of polarization so that light gets through the final filter. As soon as problems of cell life and high voltage are controlled, Kerr cells may be expected to operate in 0.01 microsecond and provide the basis for a very bright large-screen television projector.

Another device being developed as a light modular is the piezoelectric crystal. Fairchild is actively developing this technique. If a voltage is applied to a piezoelectric crystal, the crystal changes shape. This change in shape permits construction of a shutter with only one solid part, although Fairchild has experimented with using the piezoelectric to drive a column of fluid which is used as a light modulator. A new product announcement from one of these areas could cause such a unit to appear in the IMCC instead of an Eidophor or Light Valve.

Light Spot Pointer: DuMont has developed a display system for the Signal Corps using individual projectors for each symbol. Each projector contains a light source and a metal symbol disc containing 200 symbols (or more). Each disc is servo positioned to select the symbol. The position of the symbol on the screen is controlled by translating the projector lens with an X-Y servo. This positioning can be done in a dynamic manner, and each symbol can be controlled independently. Color is provided by inserting a filter in the light beam. Naval Electronics Laboratory has a display system using 17 such projectors (without the automatic symbol changing feature). The simpler projectors cost $1,200 while the complex models cost $3000. Similar devices are also under development by Kollsman Instrument. Such projectors would be ideal in the IMCC to display changing situations and relationships such as predicted impact points, vehicle locations, etc. with tracks, reference backgrounds, and other data superimposed on the same screen from scribers or background projectors.

5A.3.2 Non-Projection Devices

Large non-projection displays are of two types; cathode ray tube and matrix.

5A.3.2.1 Cathode Ray Tube

The fast response, ease of driving, and high brightness characteristics of cathode-ray tubes have led to development of a wide variety of small tubes. Production of a truly large cathode ray tube has been held up by the problem of large envelope size, high costs, and high vacuum considerations. Recent development of giant transmitting tubes such as klystrons several feet high has changed the problem. Ovens and other equipment for fabricating giant tubes is becoming available, and interest in large-diameter cathode ray tubes is reappearing. Litton Industries has suggested that a ten-foot diameter CRT would cost $50,000 per unit in small quantities and less in moderate quantities. The steel cone would be 1/4 inch thick, the faceplate 4 inches thick, and the tube length would be close to ten feet. It gives promise of outstanding brightness and contrast, but is still in the early planning stage.

5A.3.2.2 Matrix Panels

Dynamic, automatically driven large displays can be obtained by forming a matrix of simple display devices such as lights or individual character digital readouts.

Philco has constructed a light bulb array having over 1000 bulbs in each row and over 1000 rows. There are three serious problems with such a display. Data storage must be provided for each element in the matrix. In the Philco board, reed relays are used. Since over one million elements exist, over one million relays are required. Another problem is heat dissipation. Each lamp takes nearly a watt of electricity. If a majority of the one million bulbs were on simultaneously, the heat and power situation would be intolerable. A final problem is the difficulty in driving the display with a computer. Unlike most of the other displays, each resolvable point must be individually controlled.

Some of the heat problems have been overcome by using light piping to separate the bulbs or using electroluminescent light sources in the matrix. The latter technique is being pursued by Sylvania, Raytheon and others.

If the number of elements in the matrix is small or if relatively few lights represent the dynamic data on a large, otherwise static display, the matrix technique can be very inexpensive. Such an approach would be the best for showing the status of the GOSS network to IMCC personnel.

5A.4 CONCLUSIONS

This appendix has described existing computer-driven display hardware available in the 1962–1963 time period. Display objectives, requirements, and system design techniques together with recommendations for a specific IMCC hardware configuration may be found in Subsection 5 of the main report.

APPENDIX 5B
RECORDING STORAGE TUBE DESCRIPTION AND OPERATION

5B.1 GENERAL DESCRIPTION

The computer output to TV converter channels described in Section 5.3.2 are based on a recording storage tube which contains two independent electron guns operating on a common image storage element. A writing electron beam is generated by one gun and deposits display information as electrical charges on the storage element. This beam writes the information in accordance with analog deflection and blanking signals which are derived from the digital control and processing equipment. The storage element retains the electrical charges and is scanned by a reading electron beam, which is generated by the second electron gun in the storage tube envelope. This beam is deflected in accordance with the scanning standards of the high resolution television system and becomes modulated by the charge patterns deposited on the storage element by the "write" electron beam. The modulated "read" beam passes on to a collector element in the tube at which it appears as a video output signal.

5B.2 PHYSICAL DESCRIPTION

The proposed display generator discussion is based on the CK7702 recording storage tube manufactured by Raytheon Company. Several other similar types are available. The CK7702 provides high resolution and has a relatively high signal output capability. Originally developed for such applications as Radar PPI to television display conversion, it lends itself well to the proposed application.

As shown schematically in Figure 5B.2-1 this tube contains two electron guns on opposite ends, one for writing on the storage element and one for reading the stored information. Each electron beam may be independently deflected according to its own requirements. Both gun assemblies are pentode structures, consisting of a cathode, (K), an control grid (G-1), a second grid (G-2) which serves as the second accelerating anode, an anode (A) and a focus electrode (FE).

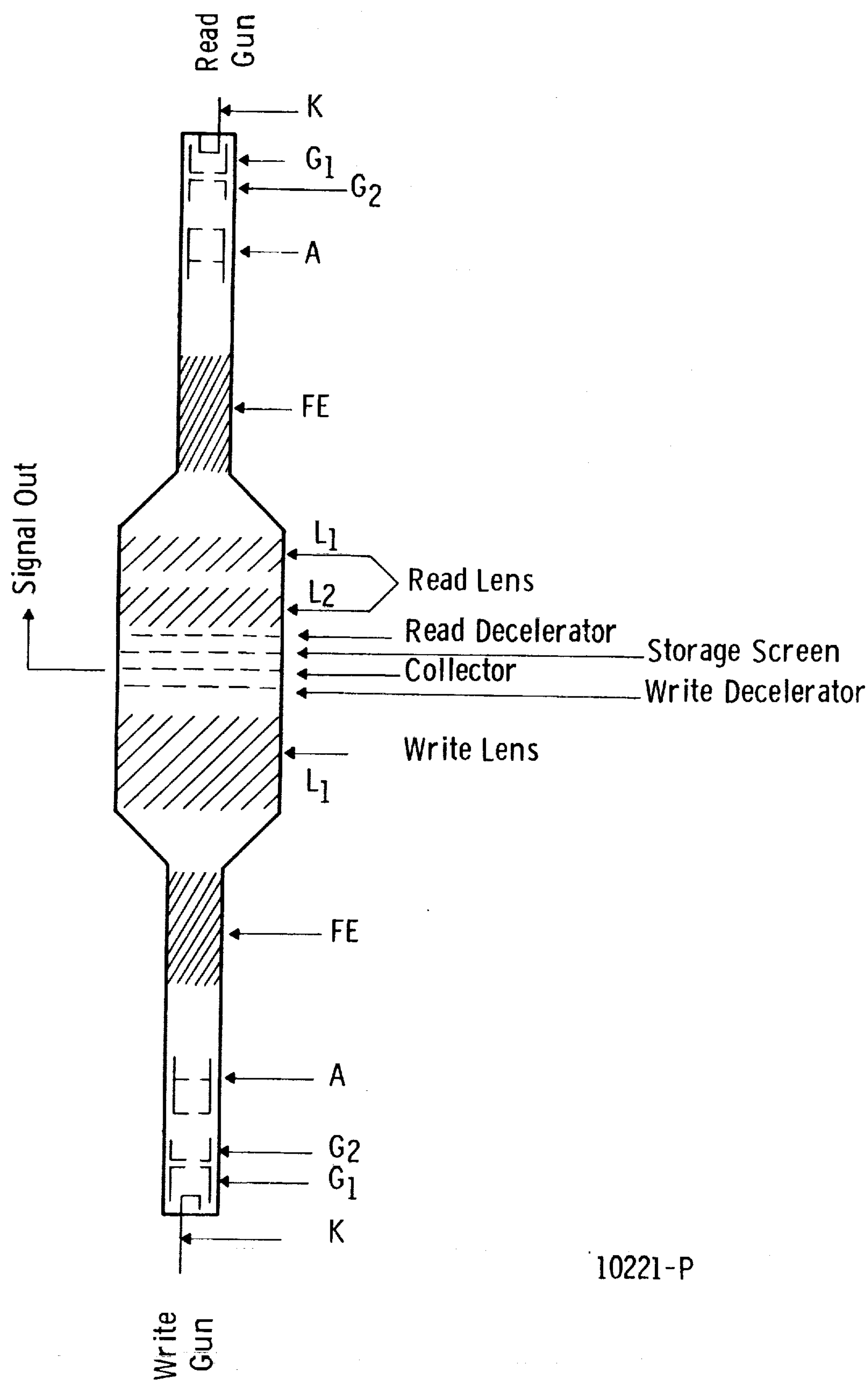


Figure 5B.2-1 Dual-Gun Recording Storage Tube

The write and read sections of the tube further contain collimating electron lens systems, each containing lens number one (L-1), lens number two (L-2) and a decelerator electrode. These lens systems ensure perpendicular incidence of both "write" and "read" electron beams with the storage screen over the entire storage screen area. The storage element is composed of the storage screen proper and the collector element. The storage screen is coated on one side with a thin layer of dielectric material which is capable of retaining an impressed charge without leakage for many hours. The electron gun which faces the dielectric is used for writing and the electron gun on the opposite side performs the reading operation. The collector electrode collects the read beam electrons after their passage through the storage screen where modulation takes place. The collector is the signal electrode of the tube and delivers the video output signal to the preamplifier.

When an electron beam strikes any material, secondary electrons are emitted. The quantity of secondary electrons is dependent on the velocity contained in the primary electrons of the beam. The secondary electron emitting surface of the recording storage tube is a dielectric material that has been deposited on a metal wire mesh or screen. This screen consists of more than 2000 cross wires per diameter. The secondary to primary emission ratio for the dielectric material used is shown in Figure 5B. 2-2. Along the horizontal axis is plotted the velocity of electrons striking the dielectric surface, or by simple conversion, the voltage potential of that surface. In the vertical axis the secondary emission ratio (p. or the ratio of the number of electrons which are emitted from the dielectric surface to the number of electrons which strike it) is plotted. Below a certain potential, called the "critical potential," each electron striking the dielectric surface drives off, on the average, less than one secondary electron; therefore the dielectric surface would be charged negatively. On the other hand, if the dielectric surface is above the critical potential, each electron striking the storage screen will cause the release of more than one secondary electron. The surface will, therefore, charge in a positive direction as long as the voltage field directly before that surface is

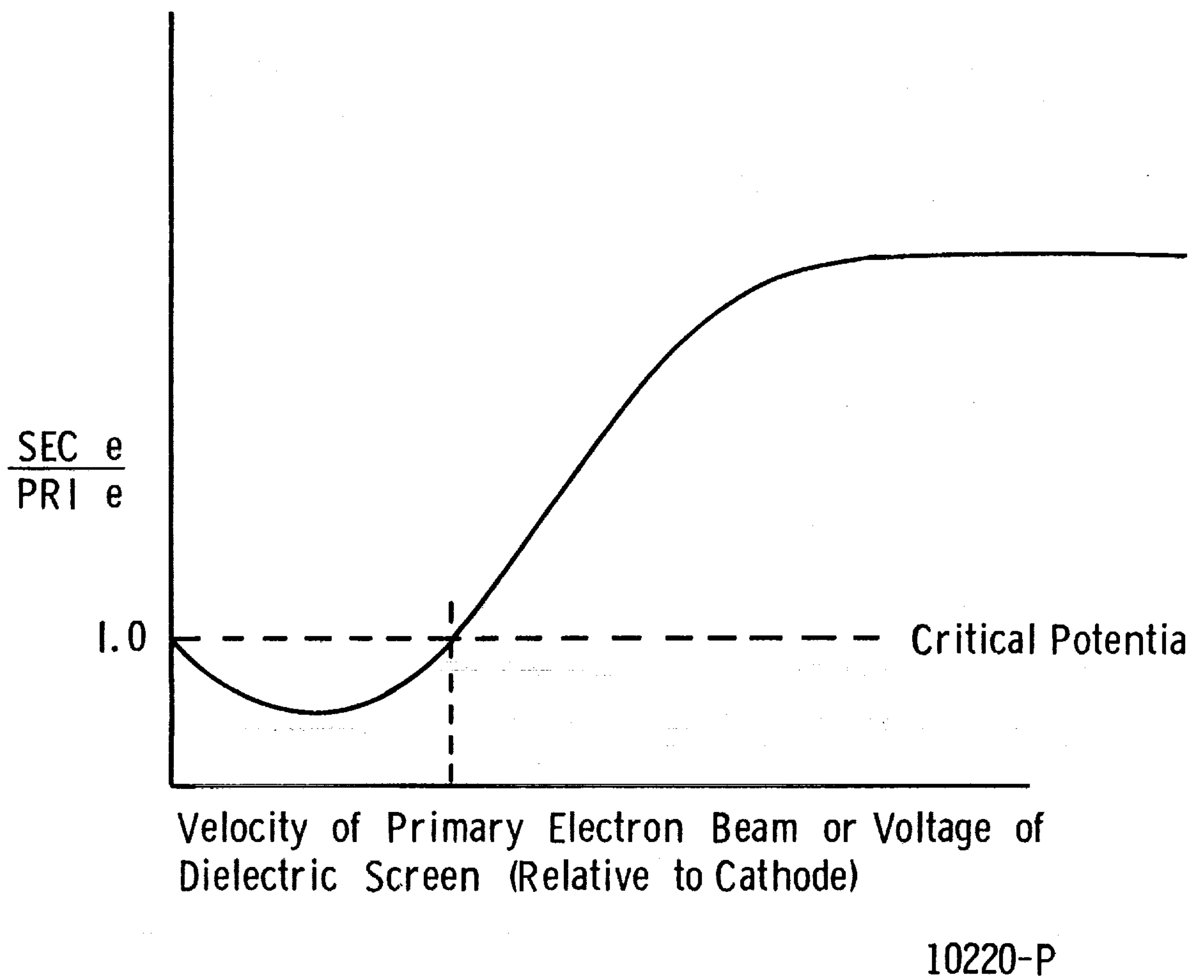


Figure 5B. 2-2 Dielectric Secondary Emission Characteristic (CK7702) sufficiently positive to draw off the secondary electrons which are emitted. The capability of retaining either positive or negative charges, depending upon the dc voltage potential of the storage surface,,is utilized in cycling the tube through its various operating modes.

The operating cycle of the tube consists of the erase, prime, write and read modes. The principle of operation may be described as follows:

a. Erasure. Erasing is accomplished by setting the storage screen voltage well above the critical potential with respect to the read electron gun cathode and scanning the storage screen with the unmodulated read beam. (It should be mentioned that either read or write electron beam may be employed in erasure. In the proposed application,it will be advantageous to employ the read beam for this function since it constantly covers the storage screen in a raster scan.) This charges the dielectric towards the potential of the storage screen, or "paints it white." The dielectric must now be primed before write information can be stored on it.

b. Priming. To prime the storage screen, the potential of the screen is set below the critical potential with respect to the read gun cathode and it is again scanned with the read electron beam. The dielectric is now charged negatively toward the potential on the storage screen and the screen is ready for write and read operation.

c. Writing. In the write mode, the potential of the storage screen must be well above the critical potential with respect to the write gun cathode. The write beam is index deflected as controlled by the outputs of the digital to analog converters in the digital control and processing equipment to the start position where a display is to be written and the beam is turned on by the unblank command signal. It then "prints" successively all the information for the display, interrupted and turned off by blanking commands whenever a crossover or retrace is required. In this "printing" operation, the beam deflection follows precisely the pattern which is set up by the digital control and processing equipment. The area where the write beam has passed over the storage screen is now charged positively and the information is stored.

d. Reading. The stored information may be read at the same time as new information is being written. The collector electrode is positive with respect to the storage screen and the read cathode, and will attract the electrons in the read beam. The read electron beam is deflected to scan over the entire storage screen in accordance with line and frame synchronizing signals of the high resolution television system. The charge pattern deposited on the storage screen dielectric now modulates this read beam on its way to the collector electrode. Where the storage screen is more positive than the read gun cathode, the beam will pass through the holes in the storage screen mesh and arrive at the collector signal electrode. Where the storage screen is more negative, the effective hole size in the storage screen mesh will become smaller and will decrease the amount of read beam current arriving at the collector. By selecting the proper storage screen voltage, the most negative areas of the dielectric (established in the prime mode) can be made to cut off the read beam from the collector entirely and thus "black level" is established. Various gray shades will be generated where the dielectric is less negative. It should be noted that the amount of secondary electrons emitted as a function of the "write" beam action is dependent on the write beam current. Therefore, modulation intensity of characters and symbols in the video output can be varied by adjusting the write beam current. In the proposed application, it is envisioned that all display information will normally be of a single amplitude, which will result in a complete cut-off of the read beam and after signal amplification and inversion, produce peak white video signal components. Provisions, however, may be made for a distinct series of three brightness steps which are generated by programming the write beam current from a 2-bit code associated with the digital display word. If desired, this feature may be used to code elements of display as to time of last up-date according to three levels of brightness in the final display.

APPENDIX 5C

PRELIMINARY PERFORMANCE SPECIFICATIONS FOR CLOSED CIRCUIT TELEVISION DISPLAY SUBSYSTEM

5C.1 SCOPE

This specification defines the performance requirements for the television display subsystem including its component signal generation equipment, all technical and distribution equipment and all display devices when connected as a complete system. Equipment specifications for the system, while not within the scope of this document, have been included for the display devices which represent the outputs of this subsystem.

5C.2 GENERAL

The complete subsystem shall provide a capability to generate, distribute and display high resolution, monochrome information with pictorial, graphical and alpha-numeric content. Signal generation devices shall include cameras (or other signal transducers) which generate electrical signals from both 3-dimensional scenes and/or 2-dimensional graphic materials via suitable optics and light sensitive transducers which are operated in a television-type raster scan. (In addition, computer display to television conversion equipment will be provided to form compatible system inputs. These devices will be covered by their own specifications). Suitable switching, distribution, pulse generation and auxilliary terminal equipment and display devices which accept an electrical input and generate a visual display for both console and group viewing shall be provided.

5C.3 PERFORMANCE SPECIFICATIONS

5C.3.1 Operating Standards

The television subsystem shall be designed to operate on the following standards:

a. Field Rate: 60 cps
Frame Rate: 30 cps (interlaced 2:1)
Line Rate: 30,870 cps
Lines per frame: 1029

or

b. Field Rate: 60 cps
Frame Rate: 30 cps (interlaced 2:1)
Line Rate: 26,250 cps
Lines per frame 875

or

c. Field Rate: 60 cps
Frame Rate: 30 cps (interlaced 2:1)
Line Rate: 15,750 cps
Lines per frame: 525

The exact choice of scanning standard will be made after a thorough analysis of display content in terms of horizontal and vertical resolution requirements, display density influencing character size for alpha-numeric data display and special characteristics of certain dynamic plots. (It is stipulated at this time that clear, unequivocal resolution of an alpha-numeric character display in a practical television-type raster requires incidence of ten active scanning lines. The number of rows of alpha-numeric characters which must be simultaneously presented will influence character size and thereby vertical resolution and line number requirements.) For the purpose of this system performance specification, the operating standard described under (b) has been tentatively chosen.

5C.3.2 System Resolution

System resolution is as follows:

a. Horizontal: Better than 850 lines at the center and 700 lines at the corners. Detail response at 800 lines shall be at least 30%.

b. Vertical: Better than 600 lines.

The above performance shall be measurable at any CRT display monitor in the system from any pick-up device in the system when televising a 1956 RTMA resolution chart. Vertical resolution as specified is only applicable to the operating standard described under 3.1.b.

5C.3.3 Geometric Distortion

No picture element shall be displaced from it true position by more than 2% of the display height.

5C.3.4 Sweep Linearity

Horizontal and vertical within ± 1% (EIA Method).

5C.3.5 Synchronization

(Applicable to operating standard described under 5C.3.1.b)

Synchronization shall be accomplished by means of negative horizontal and vertical drive pulses of three to five volt amplitude. No composite sync signal shall be provided within the closed circuit portion of the system.

The horizontal drive pulse width shall be 4 microseconds ± 10%. Its leading edge shall be coincident with the leading edge of blanking. Horizontal blanking shall be of 6 microsecond minimum duration.

The vertical drive pulse shall be of 15 ± 1 line duration. Its leading edge shall be delayed 2 lines from the leading edge of vertical blanking. Vertical blanking shall be of 21 lines minimum duration. (Operating standard according to 5C.3.1.b)

5C.3.6 Interlace Accuracy

Consider A, B, and C to be three adjacent scanning lines; then the value of space A-B/space B-C shall fall between the limits of 0.9 to 1.1.

5C. 3. 7 Power Source

All equipments provided shall meet specifications when connected to a source of 60 cps ± 5% single phase current at 115 volts, ± 10%.

5C. 3. 8 Electrical Channel Characteristics

5C. 3. 8. 1 Frequency Response

Frequency response of all system electrical channels including all video processing, distribution, switching and cable facilities shall be flat within ± 1 db to 17 Mcs and less than 3 db down at 20 Mcs. (Operating standard described under 5C. 3. 1. b only).

5C. 3.8 . 2 Delay Characteristics

Group delay shall be within - 0. 03 microseconds from 15 kc to 17 Mc relative to the low frequency delay.

5C. 3. 8. 3 Low-Frequency Response

Tilt and bow (low-frequency cut-off) shall be less than 3% on a 60 cps, 50% amplitude square wave.

5C. 3. 8. 4 Differential Gain

The differential gain or amplitude linearity as measured between the largest and smallest step gain shall be less than 10% of the amplitude of the larger gain for all video duty cycles between 10% and 90%. The differential gain between any two steps shall be less than the quantity:

$$\frac{10\% \times \text{difference in step number}}{5}$$

When a linear waveform at 10 steps is used as a test signal.

5C. 3. 8. 5 Hum Level

The additive hum due to the fundamental and all harmonics of the power line frequency shall not exceed a peak-to-peak value of 1/50 of the nominal peak to peak video signal. The hum modulation of the video signal due to the fundamental and all harmonics of the power line frequency shall not exceed a peak-to-peak value of 1/100 of the peak-to-peak video signal.

5C.3.8.6 Signal-To-Noise Ratio

With any channel input terminated in its nominal impedance, the output noise power over the band from 1000 cps to 17 Mc must be at least 40 db down relative to the nominal video output level.

5C.3.8.7 Transients

No periodic transient disturbance, occuring during the picture interval, which is internally generated by the equipment or its power supplies, such as cross-talk, intermodulation, etc. shall exceed a peak-to-peak value of 1/2000 of the nominal peak-to-peak video level. Measurement is to be made at the system outputs. Transient disturbances occurring during the blanking interval shall not exceed 1/20 of the nominal peak-to-peak video level.

5C.3.8.8 Gain Stability

The system gain must be constant within 0.5 db for line voltage changes over the range from 105 to 130 volts (about a nominal line voltage of 117 volts).

5C.3.8.9 Interference

The equipment shall be so designed and all distribution and transmission facilities so constructed that the output level due to conducted and radiated interference is at least 46 db down relative to the nominal system output level.

5C.3.8.10 Reflections

The reflections produced in response to a 1-microsecond-wide test pulse should be at least 46 db below the level of the test pulse in the system output.

5C.3.8.11 Channel Cross Talk

Cross talk between individual channels of the over-all system shall be at a minimum of 35 db down at 17 Mcs and decreasing with frequency at a rate of 6 db per octave to a minimum of 60 db down at frequencies below one Mc. .

5C.4 DISPLAY DEVICE SPECIFICATIONS

5C.4.1 General

Detail characteristics of individual CRT displays are not determined at this time. In general, they will be console mounted for observation by a single observer.

Group display devices for the television subsystem will rear project images (nominally 7'5" x 10' 00" in size) on transmission type screens. Light output requirements for large screen television display in this application require the use of light modulation techniques.

5C.4.2 Individual CRT Displays

5C.4.2.1 General

Individual CRT displays will be direct-view, high quality television monitors, employing cathode ray tubes with a diagonal dimension of 17 and 21 or 24 inches. The smaller devices will generally be installed in operating consoles for single observer use. The larger units may be employed at miscellaneous display positions for group viewing by more then a single observer or where the position of the observer is not fixed in respect to the monitor.

Console mounted monitors may be replaced by small projection CRT's and suitable optics with a glass screen forming the viewing surface. The utilization of such a system will be dependent on viewing conditions, console packaging design and technical consideration. For purpose of this specification, direct-view CRT monitors are considered. All applicable specifications for resolution, brightness and contrast would have to be met by the CRT projection devices also.

5C.4.2.2 Contrast Ratio

The large area contrast shall be at least 30:1.

5C.4.2.3 Resolution

Limiting resolution in the horizontal direction shall be at least 850 lines in the center and no less than 600 lines in the corners of the display. Vertical resolution shall be no less then 630 lines per display height. Operating standard in accordance with paragraph 5C.3.1.6).

5C.4.2.4 Brightness

Highlight brightness, under full contrast and specified resolutions and using a polarized glass faceplate for the CRT, shall be no less then 75 feet lamberts.

5C.4.2.5 Geometric Distortion

Geometric distortion resulting from non-linearity in the deflection circuit shall be less than 2% as measured by the EIA method.

5C.4.2.6 Aspect Ratio

Aspect ratio shall be variable between limits of 1:1 and 3:4 (height to width).

5C.4.2.7 Bandwidth

The video amplifier bandwidth shall be flat within ± 1 db to 17 Mc and less than 3db down at 20 Mcs. (Operating standards according to paragraph 5C.3.1.6).

5C.4.2.8 Gain

The video amplifier shall have a minimum gain of 200.

5C.4.2.9 DC Restoration

The video amplifier shall incorporate circuits to provide 100% dc restoration.

5C.4.3 Group Display Projection System

5C.4.3.1 Operating Standards

The projection system shall operate in the scanning standards described in paragraph 5C.3.1 of this specification. The choice of one of the given standards will be made at a later time and on the basis of additional requirements analysis. For purpose of this specification, the standard as described in 3.1.6 is assumed.

5C.4.3.2 Light Output

The projection system shall provide a minimum light output of 1400 lunens. Intensity at any point within the image area shall be no less than 75% of the maximum intensity of illumination.

5C.4.3.3 Projection Optics

The focal length of the projection lens will be determined at a later time.

5C.4.3.4 Contrast Ratio

The large area contrast ratio shall be at least 20:1.

5C.4.3.5 Resolution

Limiting resolution in the horizontal direction shall be 850 lines. The contrast ratio at the limiting resolution shall be at least 30% of the large area contrast ratio. Corner resolution shall be at least 75% of that at the center.

5C.4.3.6 Geometric Distortion

Geometric distortion resulting from non-linearity in the basic deflection process shall not be greater than 1% as measured by the EIA method. Additional distortions due to keystone modulation and optical field curvature shall be minimized with suitable correction devices. The total distortion due to the combination of all effects, electronic and optical shall not exceed 2%.

5C.4.3.7 Interlace Accuracy

Interlace accuracy shall be in conformance with paragraph 3.6 of this specification.

5C.4.3.8 Video Amplifier

The video amplifier bandwidth shall be 17 Mcs $\pm$ 1.5 db (operating standard according to paragraph 3.1.6). The amplifier shall have sufficient gain to provide full modulation from an input video signal with 25% of the nominal input signal amplitude. The amplifier shall be capable of providing at least 50% more output signal than that required for full modulation with no more than 15% differential gain. Differential gain at a level corresponding to full modulation shall be no more than 10%. (See paragraph 5C.3.7.4 of this specification which also applies).

5C.4.3.9 Transfer Characteristic

The overall transfer characteristic of the projection display from video input to light output shall correspond to a gamma of 2 $\pm$ 10%. Gamma correction circuits shall be so arranged that they may be disconnected by switch if desired.

5C.5 RELIABILITY

The system shall be designed for the maximum practically obtainable reliability. Particular attention should be paid to component operating temperatures. Design should be sufficiently conservative to allow continuous, reliable operational at ambient temperature as high as 120°F. To the maximum extent possible, modular construction shall be employed, allowing quick interchange of system components on the chassis level.

SECTION 6
SIMULATION AND CHECKOUT SYSTEM

6.1 GENERAL

The functional requirements for simulation and checkout have previously been reported in WDL-TR-E112-2, but are repeated here for continuity and to support the design concept. The design concept has been developed not only for Gemini operations but also for Apollo operations. This integration provides both a flexible design and one which is less costly than the design of independent simulation systems for each program.

6.2 SIMULATION AND CHECKOUT REQUIREMENTS

6.2.1 Simulation

One function that simulation must support is training. Briefly, the training is conceived as including the following:

a. General Training. Formal classroom training, for all mission operating personnel, consisting of Gemini (or Apollo) mission objectives, procedures, and rules; Gemini-Agena (or Apollo) vehicle operations and systems; and GOSS operations and systems. Simulation support is not necessary for this first element of training.

b. Detailed Training. Formal classroom training, for those operating personnel involved primarily in operations in the IMCC or remote sites, consisting of detailed instruction on IMCC systems and operations, and for remote site operations personnel, detailed instruction on remote site systems operations. Simulation exercises will provide procedural training primarily for "normal" operations and an understanding of equipment functions for the Control/Display System. This simulation would be of the open-loop type, but with programs set up so that the sequence of operations can be interrupted (for instruction purposes) without destroying continuity.

c. Integrated Training. After general orientation and detailed training both for the IMCC and remote sites, a short integrated training on operations for a typical mission will be conducted. The simulation for such training will be a closed loop encompassing mission control operations in the IMCC, vehicle simulator, and typical remote sites.

d. <u>Specific Mission Training</u>. For each mission, all mission operating personnel should receive instruction on specific mission objectives, changes in the vehicle and/or GOSS systems, and the operating procedures and rules. Simulation should be analogous to present Mercury exercises and should exercise all types of GOSS sites. This will serve as the final validation of procedures and rules as well as the final checkout of personnel.

Another function of the simulation system is to support the development of training exercises, procedures and rules, and the design improvement of instrumentation for control and display. For any specific mission, changes in objectives and/or in the vehicles, necessitate corresponding changes in procedures and rules, and, most likely, changes in instrumentation both at the IMCC and remote sites. Closed-loop simulation can be a useful tool in evaluating procedural and design changes. Depending on the results of such evaluations, further development and evaluation may be needed before a specific mission training exercise is conducted.

To engender as much realism as possible and to insure that there is positive transfer of training to actual operations, use of actual operating consoles rather than an off-line facility, is recommended. To permit the development and evaluation of programs, procedures and rules, and possibly design modifications in GOSS, it is necessary to have closed-loop simulation. To provide for this type of simulation, it is desirable to have actual equipment elements of a command-type "remote station" close to the IMCC, assuming that a command station includes the same data transmission equipment. (For simulation alone, it is not necessary to have a complete command-type station, i. e., the antennas and RF portions could be by-passed during simulation.) To allow a simulated exercise to be conducted in a reasonable length of time, provision must be made for running portions of the program in "fast" time. This would allow a two-week operation to be simulated, for example, in one day or less.

The necessity to prove exercises, evaluate procedures and rules, and to evaluate possible design changes, requires that two MOCRs exist, if mission schedules are such that insufficient time is available for the proving and evaluation and the subsequent specific mission training exercise for GOSS. (Refer to Section 3 of Reference 1 for additional justification for dual MOCRs.) By the same token, if the remote site near the IMCC is to be used for both operations and simulation, the remote site must be available for simulation.

6.2.2 Checkout

Checkout requirements can be treated in two categories, pre-mission and real-time requirements.

a. Pre-mission Requirements. Because of the dual configuration of the MOCR and associated support systems, it will be possible to perform pre-mission checks on these subsystems while a prior mission is still in progress. Verification of the IMCC subsystems can be accomplished either by using the simulation computer(s) or by connecting to a simulated station (these configurations will be outlined in Subsection 6.3). It is anticipated that the computer programs and simulation equipment provided for training purposes will be used to a significant degree in the checkout facilities.

   When the tracking station network is free, verification checks will be performed to provide system confidence. It is assumed that individual station subsystems will be checked on specific sites at the direction of the IMCC. The main function of the pre-mission tests will be to (1) verify the performance of communication links with the remote stations and (2) insure total and reliable performance of the alternate operational system. Where feasible, these tests will be automated and computer controlled.

b. Real-Time Requirements. Real-time requirements deal with system monitoring, fault detection and fault isolation. Strictly speaking, this aspect of checkout cannot be treated as a separate subsystem, but rather as an overall requirement which is imposed on the prime equipment as well. The equipment must have the capability of monitoring status of the GOSS network, and the capacity to detect and isolate the source of malfunction to one of the following areas: (1) spacecraft, (2) tracking station, (3) data links, or (4) IMCC. Isolation of the component and the correction of the fault are the responsibility of the affected site. A possible approach to this problem could be the use of check-words at specific times in the data cycles so that discrepancies can be readily identified. With adequate monitoring capability, the point of failure can be isolated within reasonable limits.

6.3 SIMULATION AND CHECKOUT CONCEPT

Figure 6.3-1 represents a simplified functional block diagram of the Simulation and Checkout System. It will perform the following:

a. Provide the IMCC with simulated station and spacecraft inputs for separate exercise of the IMCC. In the actual operation, data to and from remote sites pass through the communication link and the coupler, and are distributed to the appropriate computers by the input-output equipment. Computations are then performed, and the appropriate displays are activated.

   Control functions performed by the personnel pass through the buffer and selectors, on to the computers, and appropriate messages are transmitted to the remote sites.

   In the simulated operation, the simulation computer replaces the remote sites. Under the control of the simulation control console, simulated remote station responses are generated and pass through the input and output equipment to the coupler. From this point on, the IMCC behaves as it does in the actual mission; the computation equipment performs its normal functions, provides display data, and generates command messages at the direction of the MOCR. The commands are acted upon by the simulation computer so as to simulate remote station behavior.

   A similar operation occurs when DSIF station inputs are simulated. The only difference is the fact additional simulation equipment is probably necessary.

   Voice and data recorders will be used to record the simulated operation for post-exercise analysis. Tapes may also be used for open-loop simulations.

b. Provision is also made to run independent exercises at the MSC "remote site." As shown in Figure 6.3-1, IMCC inputs are simulated and are inserted at the input buffer, and the formatter performs its normal functions of accepting this data and also telemetry and trajectory data. The latter are simulated (the flight trainer is not used in this exercise). A departure from the actual station occurs in the control/display consoles. Since the site is to be used for training, two sets of station consoles are tied into the system through a switching circuit. In this way, the normal station-IMCC relation can be exercised, as can the interface between stations.

c. The simulation equipment will also provide for an integrated exercise of the IMCC, the MSC "remote site" and the flight operations trainer.

   In this case, telemetry and trajectory data are generated by the vehicle simulator, passed through the switching circuits

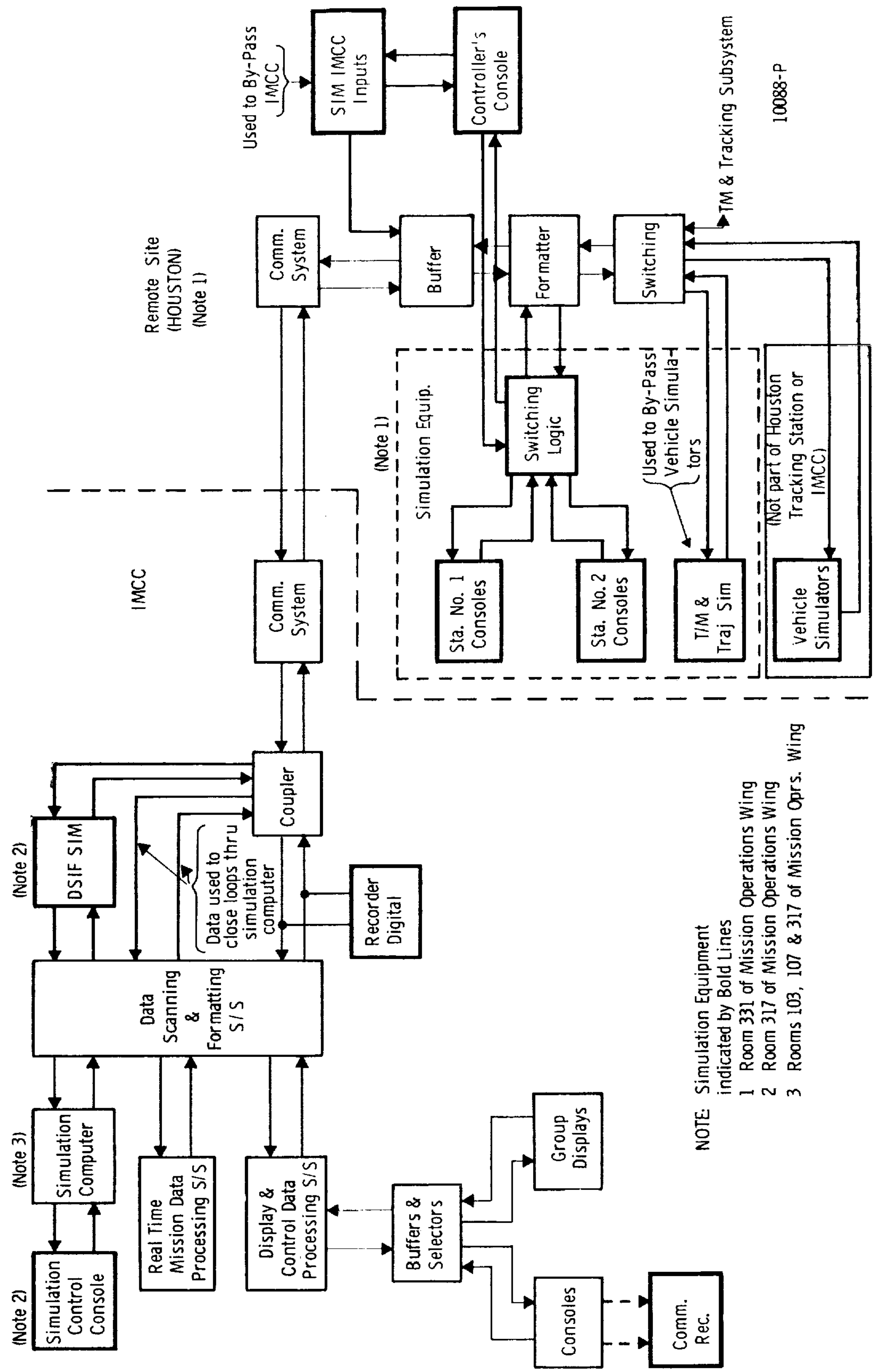


Figure 6.3-1 Functional Block Diagram of the Simulation and Checkout System Concept

to the formatter, and appropriate data are passed to the station consoles and to the communication link in to the IMCC. The IMCC behaves as it does in an actual operation. The simulation computer will be used for evaluation and contingency insertion.

d. Provision will also be made to exercise the GOSS network. While considered part of the simulation and checkout subsystem, this function will utilize the prime equipment, running through routines which will assure IMCC, remote site and network readiness.

6.4 EQUIPMENT DESCRIPTION

The Exercise Director Console will provide the director with required control and display data for simulation exercises. Also, voice simulation will originate at this point, as will contingencies. The switching and digital logic section will perform the following functions:

a. Switchover to simulation mode
b. Provision for closing loops within the IMCC
c. Provide flexibility in the simulation subsystem so as to cover a variety of operations
d. Provide for switchover to operate with the MSC "remote site"
e. Provide for integrating DSIF input simulation, then allow the simulation system to handle both Gemini and Apollo programs
f. Provide required buffering and/or formatting of simulated data.

In conjunction with this equipment, computer-controlled programs will allow the simulation to be responsive to a wide range of human inputs. The DSIF equipment will simulate inputs for these stations. The recording equipment will be utilized in simulation and checkout for post-exercise analysis and de-briefing.

SECTION 7
MSC "REMOTE SITE"

7.1 GENERAL FUNCTIONAL REQUIREMENTS

The establishment of a "remote site" at the Manned Spacecraft Center is highly desirable and will result in long-term economical advantages. It will serve the primary and secondary functions indicated below.

7.1.1 Primary Functions

Primary functions are described as follows:

a. Serve as important data source to the IMCC for simulation and checkout exercises without participation of the GOSS

b. Provide a response to simulated data from the IMCC for personnel training and procedure development in conjunction with the IMCC and the MSC Flight Trainer. This training could include the IMCC operational personnel, the flight control personnel assigned to remote sites and the astronauts.

c. Provide a means of conducting special tests for development testing of modified or new equipment for IMCC or spacecraft use.

d. Provide a means of investigating and resolving anticipated or actual interface problems between the IMCC and the operational remote sites. The above functions can be performed without the use of RF equipment.

7.1.2 Secondary Functions

A possible secondary function of the MSC site could be to support the IMCC during operational missions. This capability could be obtained by the addition of applicable RF equipment equivalent to a typical GOSS remote station. In this secondary operational support area, the functional requirements are applicable to both Gemini and Project Apollo, and include:

a. Two-way voice communication with the spacecraft

b. Reception of telemetry data from the spacecraft

c. Transmission of digital command and support data to the spacecraft

d. Tracking the spacecraft and generation of tracking data

e. Processing and time indexing of telemetry, tracking and event data

f. Two-way data and voice communication with the IMCC.

7.2 NON-MISSION REQUIREMENTS (PRIMARY FUNCTIONS)

7.2.1 Simulation and Training

The MSC "remote site" provides a valuable tool for the performance of simulation and training. Procedures and techniques can be developed and analyzed without the necessity of tying up other elements of the GOSS. Exercises can be run on actual equipments under realistic operating conditions in minimum time and at minimum expense. This does not necessarily require the use of an antenna and RF portions of a remote site.

The use of an MSC "remote site" enhances the capability for closed-loop simulation.

a. Integrated training of mission controllers (at IMCC and remote sites) is possible in accomplishing mission control operations in the IMCC, vehicle or mission and part task flight simulators, and typical remote sites.

b. Use of actual operating consoles rather than off-line facilities are recommended in closed-loop simulation.

c. Closed-loop simulation supports the development of training exercises, procedures and rules, utilizing actual equipment elements of a command type station including data processing and transmission.

7.2.1.1 Network Simulation Exercises

The requirement for conducting network simulation exercises by use of the MSC "remote site" is believed to be an additional reason for its inclusion within GOSS. Operational methods, procedures, and techniques can be evolved, analyzed, and evaluated by either limited or full-scale network simulation exercises. Much of the work can be more readily accomplished at the IMCC in conjunction with the "remote site", in lieu of use of the entire GOSS network. Parallel information flow paths can be set up, and multiple cross-checking of the data done on the computers at the IMCC computation center.

Several areas of network simulation include communication switching, routing and processing, contingency procedures, the hand-over problem, multiple vehicle acquisition and tracking, and rendezvous and docking techniques. By use of closed-circuit television, the operation of the "remote site" can be monitored in the MOCR. In this manner, the effects of various random and bias errors introduced into the network can be readily observed and methods developed for reducing these errors.

7.2.1.2 Personnel Training

To allow maximum benefits to be derived from training of remote site personnel at the MSC "remote site," its configuration should be a composite of all the remote sites. (Space and other operational considerations may limit the degree of duplication of other remote site equipment.) In this way, the personnel could be completely familiarized with all the on-site equipments, and more thoroughly understand the interface problem between the sites. A substantial saving in money and time also results from having the capability to train site personnel at a central location in the United States prior to sending them to an overseas site.

Even greater advantages may well result from being able to transfer personnel from various areas in the IMCC (MOCR, etc.) to the "remote site". This switching could be done on a daily basis, or by mission phases, to enable operations personnel to become intimately acquainted with all phases of the overall operation, and to obtain a better understanding of the problems encountered at various positions within the network. Periodic critiques can be held, and the results of and problems encountered in network simulation exercises discussed in detail. Manning requirements can be evaluated and reviewed as new operational procedures are developed.

7.2.2 System Improvement Testing

By careful and logical design, the "remote site" can provide a valuable facility for system improvement testing. New equipments for use in the IMCC or the spacecraft can be evaluated under realistic operating conditions.

Modifications to existing procedures can be developed and analyzed without disrupting the operation of a tracking or command station. The detailed interface between telemetry, high- and low-speed data, and the communication network can be examined by detailed tests and computer analysis, and the various parameters changed to optimize the performance. Noise and interfering signals can be introduced into various subsystems and their effects on network performance, and on displays and recording equipment evaluated.

7.3 MISSION REQUIREMENTS (SECONDARY FUNCTIONS)

7.3.1 General

It is recognized that the primary functions of the "remote site" instrumentation at the IMCC/MSC location are concerned with IMCC checkout, mission simulation, and flight control personnel training. These functions could be implemented without providing actual operating capability; i. e., a typical remote site facility could be instrumented without provision of the actual RF space-ground communication and tracking equipment.

A strong argument can, however, be made for the addition of such RF capability to provide a fully operational site at the IMCC. Such addition would have several advantages:

a. Direct support capability for the IMCC would be highly desirable. During the phasing-in of new data processing and communication equipment into the existing Mercury network stations, the network may not be fully modified to provide the required information. Therefore, this station is the best place from which to provide the real-time data for IMCC use, at this time.

b. Even after the network had been modified and updated, the "remote site" would be capable of providing real-time data to the IMCC which would alleviate the demands placed on other sites for transmission of data on a real-time basis during some phases of a mission.

c. Mission profiles for Gemini indicate that the MSC location would provide contact with the vehicle during the critical early and late orbits (1-4 and 14-18, respectively), where real-time contact and high-data-rate reception and transmission without the constraints of delayed or low-speed communication circuits, may be desirable. During the Apollo Missions, the site could provide back-up to the Goldstone DSIF site, which may be involved in support of other deep space instrumentation probes.

d. The location of an operational site at the MSC would be equivalent to the present configuration of the Mercury network, where both an operational site and the Mercury Control Center are co-located

e. Even if a decision is made to defer the implementation of the operational capability until some later time, it is still appropriate to include RF capability in the present planning. This will permit appropriate integration of the instrumentation required for the simulation site with operational RF equipment. It further will establish siting criteria which could be used to constrain the future development of facilities which would interfer with this capability.

The MSC remote station can support both near-earth and lunar missions. Due to the major differences in support requirements for the two types of missions, it would be desirable to establish a compromise in the functional capabilities of the station. Thus, it would not appear justifiable to impose a requirement for precision tracking for near-earth missions since sufficient tracking data is generated by the precision tracking systems at the other remote stations of GOSS to accurately compute the orbital parameters of the spacecraft. However, it is desirable to provide an angle tracking capability to allow reliable reception and transmission of information between the spacecraft and the station. The accuracy of the orbital parameters computed at the IMCC will provide sufficiently accurate antenna pointing information to allow acquisition of the spacecraft transmission, and, therefore, a special acquisition aid is not required.

For lunar missions, it does not appear feasible to require the MSC remote station to receive video bandwidth information, due to the aperture requirements of the required antenna. Reception of the video bandwidth information from the spacecraft during lunar missions could be performed by DSIF. However, the actual use of the DSIF at Goldstone, California, may not permit its use for tracking. Therefore, this requirement may be unposed upon the station at MSC unless future developments dictate otherwise. In any event, the MSC "remote site" could serve as an alternate site (to Goldstone DSIF) with somewhat limited lunar capabilities with respect to TV reception. A more detailed description of the mission requirements per station function is contained in the following paragraphs.

7.3.2 Tracking

The requirements for tracking spacecraft at both lunar and near-earth distances differ considerably from the standpoint of tracking rates and system sensitivity.

7.3.3 Reception and Transmission of Voice

Near-earth missions will require two-way voice communication between the MSC remote station and the spacecraft at both VHF and HF. It is anticipated that, from a performance requirement standpoint, the voice communication system will be similar to that utilized in the Mercury program, with the exception of the antenna systems. However, VHF and HF elements could be added to the tracking antenna for voice transmission. For lunar missions, the voice communication system must utilize the S-band frequency and bandwidth assigned to the Apollo voice communication mode.

The mission requirements for near earth voice communication can be listed as follows:

a. Frequency
   1. 275 - 300 Mc (VHF
   2. 10 - 20 Mc (HF)
b. Modulation
   1. AM at VHF
   2. AM at HF
c. Receive
   1. VHF antenna - use tracking antenna for VHF
   2. HF antenna - to be defined
   3. Surface receiver sensitivity
      (a) 145 dbw at HF (16 kc BW)
      (b) 140 dbw at VHF (6kc BW)
d. Transmit
   1. VHF antenna: quad-helix for VHF
   2. HF antenna to be defined
   3. VHF ground transmitter: 100 w (20 dbw)
   4. HF ground transmitter: 100 w (20 dbw)

The mission requirements for voice communication during lunar missions will be defined as spacecraft communication system information becomes available.

7.3.4 Reception and Transmission of Data

Mission requirements for the reception of data at the MSC remote station include reception of PCM/FM telemetry data at both VHF and S-band frequencies.

Pending additional information relative to the Apollo telemetry system, it is assumed that, with the exception of frequency, receiving system sensitivity, and instrumentation schedule, the requirements will be similar. Thus, it would appear that the only difference in requirements will be from an RF standpoint, and the same PCM processing equipment can be used for both missions.

The transmission of digital data to the spacecraft for near-earth and lunar missions will be assumed to be similar with the exception of power and frequency, until additional information is obtained relative to the Apollo up-data link. In both cases, the same tracking antenna can be equipped with transmitting elements for transmission of data to the spacecraft. Mission requirements for the telemetry and up-data subsystems are listed as follows:

a. Telemetry
   1. System sensitivity - to be defined (tracking antenna will be used for both lunar and near earth missions)
   2. Frequencies
      (a) 225 - 260 Mc near earth
      (b) 2100 - 2300 Mc lunar
   3. Modulation - PCM/FM
   4. Bandwidth - to be defined

b. Up-Data
   1. Transmitter power
      (a) 10 kw - Gemini
      (b) 2 kw - near-earth Apollo
   2. Antenna
      (a) quad-helix or equivalent mounted on tracking antenna for near-earth missions
      (b) S-band radiator mounted on tracking antenna for lunar missions

3. Frequencies
   (a) 400 - 450 Mc near earth
   (b) 2100 - 2300 Mc lunar
4. Modulation - PCM/FM

7.3.5 Data Processing

A data processor at the MSC remote station must process all data which flows between the IMCC and the station and must perform the following functions:

a. Separating the PCM telemetry data stream into data points and distributing the digital data points to displays and/or buffer storage for transmission to the IMCC; selected data points will be processed in real time while other data points will be stored on magnetic tape.

b. Test of selected telemetry data points against prescribed limits of frequency and amplitude and routing of the data point to the IMCC if the point exceeds the prescribed limits.

c. Composition of summary messages such as spacecraft status, crew status, etc. as determined from telemetered data

d. Formating of telemetry, tracking and station status data for transmission to the IMCC at rates which are compatible with the bandwidth of the communications data circuits.

e. Process acquisition data received from the IMCC and furnish antenna pointing information to the antenna systems.

f. Process command and support data received from the IMCC and furnish this information to the up-data transmitter system.

g. Storage of selected information for recall by the IMCC if so required.

Assuming the above functional requirements are valid, there are two areas which must be resolved. These areas are: (1) the degree of computation at the remote station, and (2) the interface between the telemetry decoders and the communication terminal equipment. Current concepts for remote station data processing indicate that very little, if any, computation will be required at the remote station. The integration of the communication terminal equipment and the telemetry decoders requires a division of functional requirements. Thus, for the communication interface, it is most feasible to provide off-the-shelf error control equipment as a part of the communication system rather than impose error control requirements on the data processing subsystem. Insofar as the telemetry interface is concerned, it would not be feasible to duplicate such functions as bias test and adjust in the data processor since these functions are available in existing telemetry systems and would impose severe programming requirements on the data processor. However, the data processing system should duplicate the decoding function of the telemetry decoder. This function would not present severe programming requirements and would add flexibility to the system.

The bit rates and format of the information which will be handled by the data processing subsystem have not been finalized. Preliminary analysis of information flow requirements indicates an input of up to 67,000 bits-per-second and an output of up to 2400 bits-per-second, with the bulk of the input being 8-bit telemetry words. A storage capability of up to 180,000 bits-per-second will be required, which implies the use of two or more tape transports. Word length, memory, cycle time and other specific requirements for the data processing function will be defined in subsequent revisions as additional information relative to types and rate of information flow becomes available

7.3.6 Timing

Timing requirements for time indexing tracking, event, and other data, as well as for display and sequencing and synchronizing of equipment at the MSC remote station, can be satisfied by the timing signals generated at the IMCC and transmitted to the remote station. See Section 4.4.4 for details on the IMCC basic timing system.

7.3.7 Surface Communication

The MSC remote station must duplicate the communication terminal equipment of other remote stations of GOSS if it is to perform its simulation functions adequately. This requirement involves the use of high-speed and/or low-speed data circuit terminal equipment and the associated error control and decision feedback equipment, as well as teletype and voice circuit terminal equipment. Requirements for surface communication include:

a. Full-duplex voice communication
b. 60-WPM and/or 100-WPM teletype for use during simulation and training periods
c. Low-speed data reception and transmission at 30 to 100 bits-per-second
d. High-speed data reception and transmission at rates up to 2400 bits-per-second
e. Error control and decision feedback for data circuits.

Current information indicates surface communications between the IMCC (Rooms 107-109 of the first floor) and the remote stations (in Room 331 of the Third floor) can be provided by equivalent land lines as indicated above.

7.3.8 Displays and Controls

Displays and controls at the remote station will be limited to those required for operation of the station. However, if the current development of the GOSS for the Gemini and Apollo programs indicated the desirability of backup mission control functions at remote stations, the MSC station will be required to conform to the configuration of the GOSS remote stations.

Minimum display and control requirements will include those necessary for acquiring and tracking the spacecraft, GMT and time event displays, monitoring displays for data received from the spacecraft and from appropriate receiving equipments, monitoring displays for command verification and controls for retransmitting command data to the spacecraft if necessary or requested, and equipment status displays.

7.4 REMOTE SITE CONFIGURATION

7.4.1 Simulation and Checkout (Non-Mission)

A configuration of the MSC "remote site" for non-mission operation is described in Subsections 7.2 and 7.3. This phase of the operation does not require the RF portions of the "remote site" equipment.

7.4.2 Mission Operations

A typical MSC "remote site" configuration which could provide the desired operational capability is shown in the simplified block diagram of Figure 7.4.2-1. This equipment will be located in Room 331 of the Mission Operations Wing.

7.4.2.1 Proposed Integrated VHF-UHF Antenna Arrangement

To meet the requirements of both Gemini and Apollo, the use of a 40-foot, two-axis parabolic reflector antenna is recommended. This antenna would be equipped with multiple collimated feeds, including associated diplexers and filters, to allow transmission, reception, and monopulse con-scan tracking at 225—300 Mc (for Gemini missions) and at 2.1—2.3 Gc (for Apollo Missions), and transmission at 400—450 Mc. Crossed dipole feeds are used in the VHF and UHF bands, whereas a waveguide con-scan feed is employed at the microwave frequency. A simplified functional block diagram of an integrated antenna feed system is shown in Figure 7.4.2.1-1. The antenna control circuitry would allow both manual and automatic "tracking," using either the con-scan or the monopulse system, and would include provisions for slaving the antenna to one of the computers in the IMCC. Large antennas with similar multi-band transmitting-receiving-tracking capabilities have been developed and fabricated and are currently in operation on other space programs.

A tracking radar is not considered absolutely necessary since adequate antenna "pointing" data will be computer-generated, based on trajectory data received from other network tracking stations. For the terminal

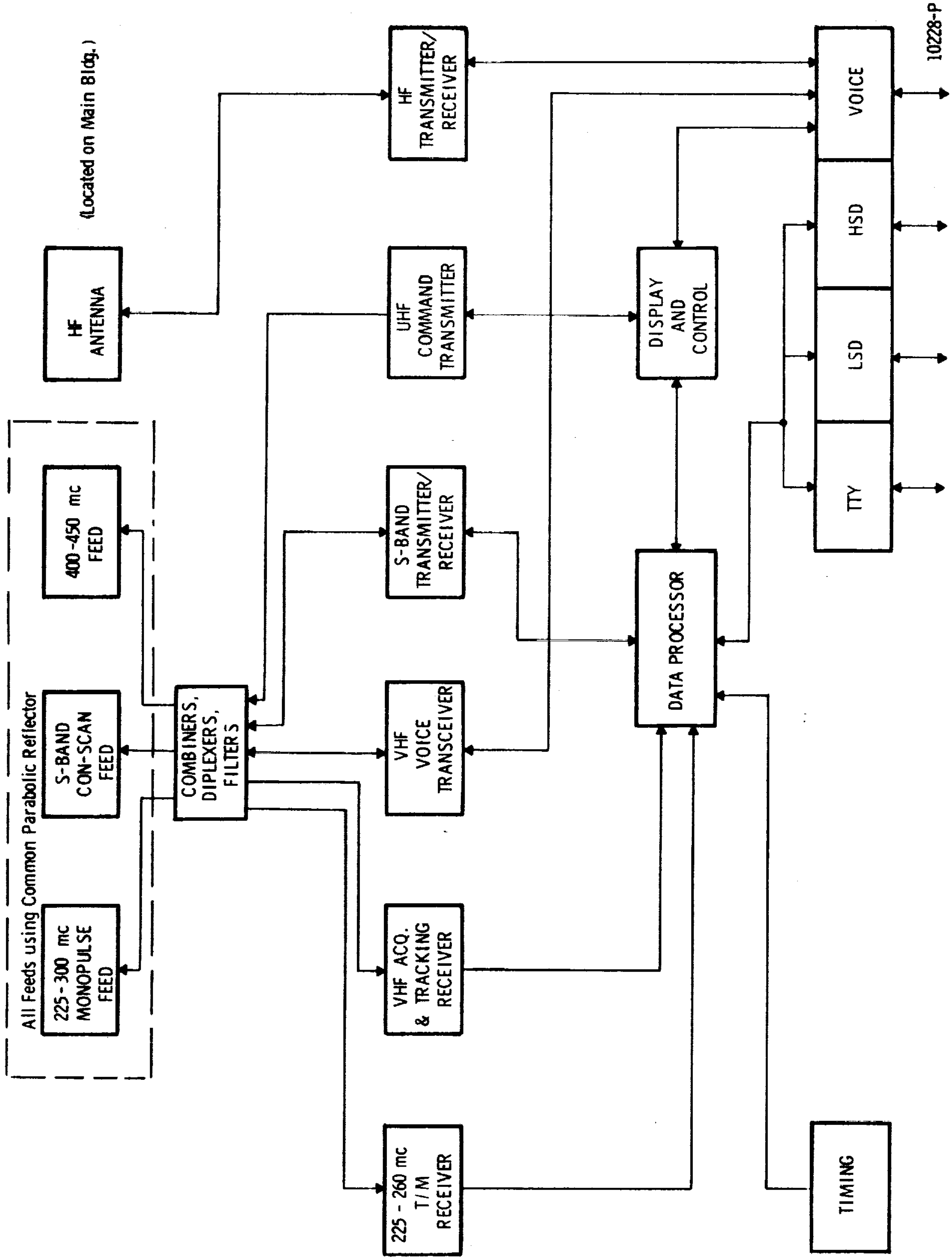
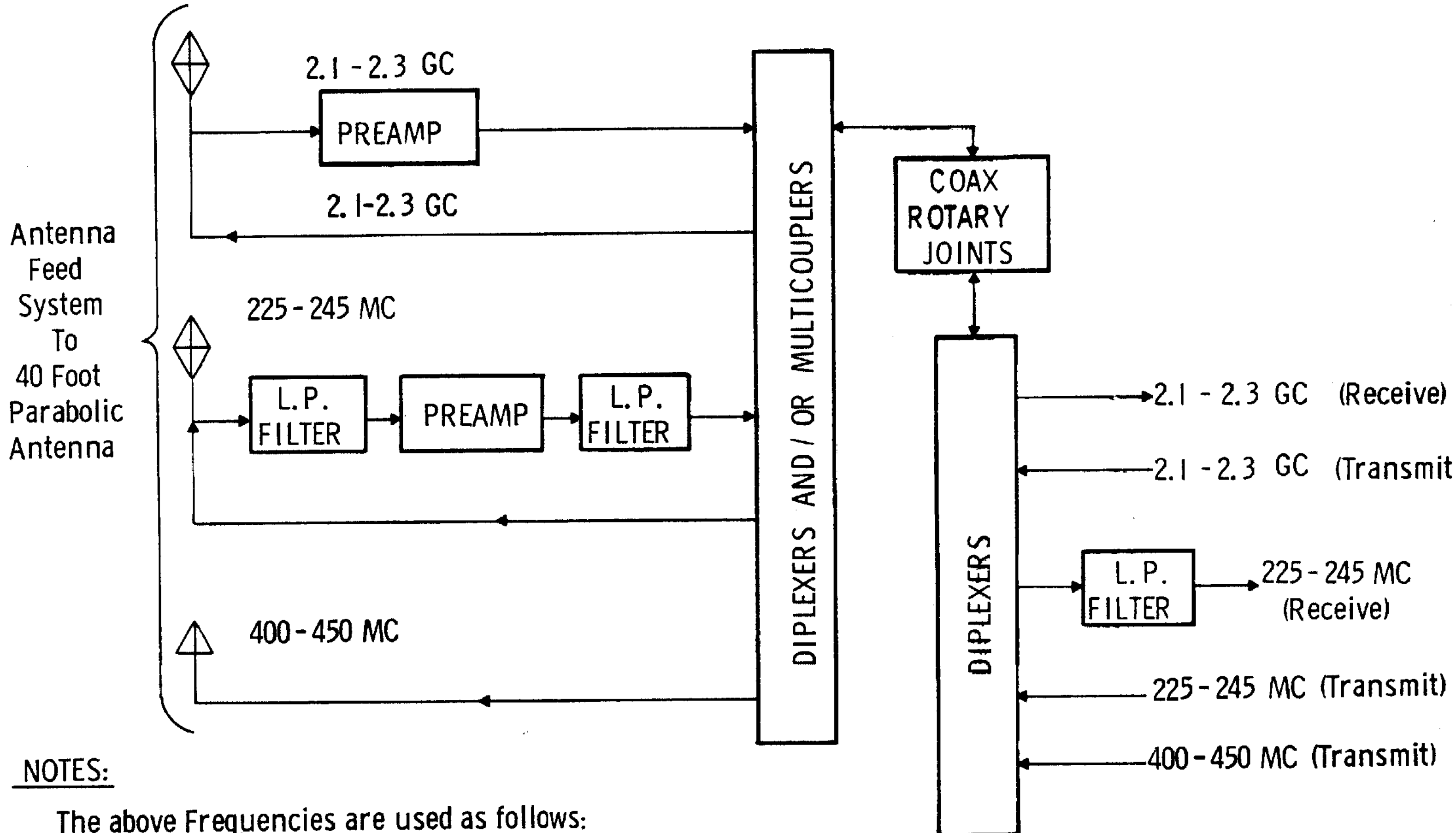


Figure 7.4.2-1 Functional Block Diagram of the MSC "Remote Site" Configuration



NOTES:

The above Frequencies are used as follows:

2.1 - 2.3 GC Apollo	Transmit: Voice, Ranging Receive: Voice, Ranging, Telemetry
400 - 450 MC Gemini	Transmit: Command
225 - 300 MC Gemini & Apollo	Transmit: Voice Receive: Voice, Telemetry, Acquisition Recovery Beacon

10091-P

Figure7.4.2.1-1 Integrated Antenna Feed System (MSC) docking phases of rendezvous, when both vehicles are in radio sight of the station, duplicate telemetry reception equipments will, quite likely, be required.

7.4.2.2 Receiving Subsystems

A sufficient number of VHF and HF receivers are furnished to permit simultaneous reception (with backup) of all voice and telemetry channels. Switchable or plug-in IF and demodulator/video amplifier modules are recommended to facilitate selection of the optimum IF or video bandwidth for the type of data being received, and to enable the best demodulation method (phase-lock-loop or synchronous detector) to be used.

The HF receivers recommended for use at a remote site are high-performance military-type communication receivers tunable over the 10- to 20-Mc range and having a sensitivity of 1 microvolt or better for a 10 db signal-to-noise ratio. These receivers should be highly stable and selective, and capable of CW, AM, and SSB reception.

The VHF receivers should incorporate provisions for selection of IF bandwidths ranging from 10 to 50 kcs for acquisition to 1 to 3 Mcs for digital telemetry. Video bandwidths are comparable, and choice of filter characteristics, such as Gaussian, should be available. The noise figure should be 4 db or less to provide an adequate IF signal-to-noise ratio at maximum spacecraft range.

The 2.1-to 2.3-Gc receivers should employ low-noise TWT or parametric amplifiers to enable reception of data at lunar distances. Ultra-stable crystal-controlled local oscillators are recommended to allow Doppler ranging techniques to be used, and to permit the bandwidth to be reduced to the practical minimum, consistent with the transmitted RF bandwidth and frequency stability. The receiver noise figure should be 2 db or less, and the local oscillator stability for Doppler or psuedo-random noise ranging should be at least one part in 10^8.

7.4.2.3 Transmitting Subsystems

For Project Gemini, a 400- to 450-Mc command transmitter and command encoder will be required. When Gemini is phased out and Apollo becomes operational, this transmitter will be replaced by a 2.1 to 2.3-Gc transmitter for use with DSIF transponders. Since a 40-foot reflector having a gain of approximately 30 db at 400 Mc is recommended, it is not necessary to use 10 kilowatts of RF. A lower-power (2 kw), more stable transmitter, with features not presently furnished by the FRW-2, could be provided for Gemini missions. Use of the 10 kilowatt RF power output at 2.1 - 2.3 Gc is recommended, however, for Apollo, since it would permit the use of presently available, high performance, wide-band FM transmitters similar to those used on other current programs.

HF transmitting equipment, similar to those to be provided for the other sites, should be furnished for this MSC "remote site."

The use of a log periodic antenna array, controllable both in azimuth and elevation, should be evaluated as to its capability to improve HF communication at ranges greater than those presently obtained in Project Mercury. The use of a directional antenna would also aid in reducing interference from thunderstorms and similar atmospherics, and would reduce interference from unauthorized or adjacent channel transmissions.

7.4.2.4 Radar Subsystem

The requirements for radar ranging and tracking at the MSC "remote site" is not sufficiently clear-cut at this time to substantiate recommendations for a radar installation. Sufficient ephemeris data and computer-derived antenna pointing information will be available to allow acquisition and tracking by means of the AGAVE, quad-helix, or forty-foot antennas

7.4.2.5 Control/Display Consoles

The control/display consoles should reflect the latest advances in the state-of-the-art, including those of human engineering. Console design and implementation should allow test and evaluation of special display or control components without materially affecting the normal site operations. Consoles for a remote site flight control team will also be required for the conduct of simulation training and exercises.

7.4.2.6 "Remote Site" Data Processor

A study is continuing to determine the specific requirements and configuration of a remote site data processor. At this time, it will be assumed that some preliminary form of semi-automatic data processing equipment will be required for Gemini. By a judicious system concept employing modular building blocks, a more advanced form of data processing equipment may be evolved, if required, to serve the future needs of Apollo.

The remote site must receive and process both the real-time and stored telemetry transmitted from the Gemini and/or Apollo spacecraft. No requirement is envisioned for processing the delayed telemetry data at the rate at which it is received (112.64 Kbps for Gemini). It is assumed that this data will be recorded and played back at a rate compatible with the real-time telemetry equipment. Preliminary analysis of information flow requirements for the rendezvous missions of Project Gemini indicates a maximum information rate of approximately 67,000 bps will be generated by remote station equipments, including telemetry data (50.2 Kbps for Gemini real-time telemetry and 16.384 Kbps for Agena real-time telemetry) digital tracking data, status data, etc. This rate, if not compressed, would represent an excessive load factor to the Communication Processor at the IMCC, as well as exceeding the capabilities of the HSD communication circuits. Therefore, it is necessary that a data separation and compression function take place before the telemetry information is presented to the IMCC Communication Processor and the Input-Output Data Scanning and Formatting Subsystem. This implies that a data processor is required at the remote station to perform this function. In this manner, the IMCC "remote site" can be treated the same as any other site, both in the operational mode and in simulation exercises, and all local telemetry display functions can be generated on site.

During simulation exercises, it is envisioned that the IMCC "remote site" may be required to act in the stead of any or all types of GOSS network stations. In this capacity, the local site would produce the usual mission tracking and telemetry data for transmission to the IMCC. A data processor, like those used at other remote sites, would generate (or control the release of) telemetry data in the mission format, receive antenna pointing information and data for "transmission" to the spacecraft and/or rendezvous vehicle, and return "tracking" data to the IMCC. It would also operate in the normal fashion in processing the simulation data for local display.

7.4.2.7 "Remote Site" Communication Equipment

a. Introduction. In the following discussion the "remote site" is assumed to have the following communication facilities:

1. High-speed data
2. Voice
3. Teletype

It is also assumed that the means of communication between the IMCC and the local "remote site" (Room 331 of Mission Operations Wing) shall be via on-site cable(s). All (land line) communications should be a 4-wire full-duplex circuits allowing simultaneous transmission and reception.

b. Equipment Descriptions

1. High-speed Data Equipment. The high-speed equipment required for the transmission of serial bit stream data consists of a data encoder, a data transmitter, and line amplifiers.

The data encoder accepts binary bit stream information from the data processor buffering equipment and arranges it into "data blocks." The encoder also encodes the data block using an effective class of error detecting code structure such as "cyclic group coding." It then initiates transmission of the data (serially) to the data transmitter. The high-speed data transmitter receives the binary data from the data encoder, and by appropriate modulation techniques, transmits this information via land lines to the IMCC. Line amplifiers are provided at the output of the data transceiver to provide impedance matching and drive capability as dictated by line and distance requirements.

The high-speed data equipment, required for the reception of serial bit-stream data, consists of a buffer amplifier, a data receiver, and Error Detection and Decision Feedback Equipment (EDDF). The buffer amplifier provides buffer capability as dictated by line level and impedance requirements.

The data receiver receives the modulated analog signal from the buffer amplifiers, and through appropriate demodulation techniques, converts the information to a dc level change code (serial binary) which is supplied as an input to the data decoder. The data receiver and data transmitter operate at a binary bit rate of 2400 bps over a 3000-cps, voice-quality line.

The EDDF accepts the serial binary output from the data receiver and arranges the information into data block format. The data block is then checked for errors by means of the coding structure used. If no errors are detected, the data is transferred (in parallel) into the data processor buffering equipment. If errors are detected, three modes of operation are available:

(a) The EDDF calls for re-transmission of the data.

(b) The EDDF "drops" the incorrect block and accepts the next data block.

(c) The EDDF error codes the data block and shunts it to the data processor in the normal manner.

2. Data Processor Buffering Equipment. The buffer equipment for the data processor will convert the asynchronous inputs of the communication system to the synchronous rate of the data processor. The storage capability will be determined by system word length and access time of the data processor.

3. Miscellaneous Equipment

(a) Code Converters. Appropriate code converters will be required to allow the transmission and reception of data and text messages from Baudot code teletype terminal equipment in serial bit-stream form over the high speed data lines. This equipment will be used in conjunction with the data processor.

(b) Recording Equipment. Appropriate recording equipment will be provided to record all high-speed data, voice and TTY communication traffic. These recorders will take the form of magnetic tape recorders oscillographic recorders, pen recorders, ..., and video tape recorders. The recording facilities should not only duplicate those at other remote sites, but provide additional capability to impelement extensive simulation and evaluation exercises. Video tape recorders or thermoplastic recorders, for the experimental recording of real-time television signals from the capsule, would be a valuable test feature and should also be provided.

(c) Voice Communication. The voice communication system within the "remote site" will be required to provide not only a reliable ground facility for intra/interstation calls (both conference and private) but also the means for direct voice communication between the ground station and the spacecraft. Therefore, the 225- 300-Mc monopulse feed system on the 40-foot antenna will be employed together with its associated diplexers and filters, and the VHF voice transceiver. The ground communication portion of the voice net will require standard terminal and distribution equipment which should be under direct control of a voice communication controller (console) who will monitor quality and routing of all voice transmission. In the event voice communication between the IMCC and the "remote site" are by land lines, terminal amplifiers will be required to provide impedance matching and level control.

(d) Teletype Equipment. Standard teletype equipment (such as Teletype Corp. 28 ASR) will be required for administrative communication between the IMCC and the "remote site." Auxiliary tape reperforating and reading equipment may also be required to expand the capabilities of the TTY facility. Availability of code (D/TTY and TTY/D) converters will undoubtedly be required to provide additional flexibility, in that this will allow the transmission and reception of serial bit binary data over the TTY circuits. The use of TTY circuits for data transmission will undoubtedly be required during non-mission periods and perhaps also in some simulation exercises.

SECTION 8
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